SYSTEM OF CHEMISTRY

OF

INORGANIC BODIES.

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IN TWO VOLUMES.

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PREFACE.

THE object of this book is to lay as complete a view as possible of the present state of Chemistry before the British Public. Instead of a new edition, it might, without impropriety, have been styled a new work. For at least nine-tenths of the whole has been written anew. The arrangement has been considerably improved and simplified, and rendered as nearly scientific and natural as the present state of the science will admit.

Though I have given the title of *Inorganic Chemistry* to the present work, yet I thought it advantageous to include in it an account of all the *Acids* at present known, even those derived from the animal and vegetable kingdoms, because I wished to make it a work to which my practical Students could apply for information in every department of Elementary Chemistry, and many of these acids are occasionally employed in Chemical researches. I intended also to have introduced an account of all the lately discovered compound alkaline bodies belonging to the vegetable kingdom. But I found that this could not be done without swelling the size of the second volume too much, or obliging me to omit some part of my account of the Salts; which I was unwilling to do, because an accurate knowledge of these bodies is indispensable to the Practical Chemist, and I was not aware of any work in the English language where these important bodies have been described in detail. I thought it better, therefore, merely to give a list of the compound vegetable alkaline bodies in page 259 of the second volume, and to reserve the description of them to a separate work, which I propose to publish, on the Chemistry of *Vegetable Bodies*. I reserved them for that work with the less regret, because none of them are at present employed as a reagent by the practical Chemist.

On turning over the pages of these volumes I observed several errata; some of them due to my own negligence and some of them errors of the printer; but I have not thought it worth while to draw up a table of errata, because the attentive reader will find no difficulty in correcting them for himself. In the table of the weights of atoms, printed in page 12 of the first volume, there are some erroneous numbers; which the reader will easily discover by comparing it with the table of the atomic weights printed in the Appendix to the first volume. These errors were occasioned by my trusting to the numbers which I myself had deduced from my own experiments. But when I came to investigate the subject in detail, in preparing the subsequent parts of the book, when I compared my own results with those of other labourers in the same field, and when I had recourse in all difficult cases to new experiments, I found reason, in four or five cases, to alter the numbers which I had originally fixed on. The discovery of truth being the only object of importance, I have never in any case hesitated to sacrifice my own particular views, when the investigations of others have produced sufficient evidence that they were unsound. I trust, therefore, that my atomic numbers, as given in this work, (though it would be too much to affirm that they are all accurate), will yet be found much nearer the truth than those that preceded them—as near, indeed, as the present state of Experimental Chemistry will enable us to go.

To render the great number of new facts and new classes of bodies, which have recently made their way into Chemistry, intelligible to the reader, I was frequently under the necessity of contriving new terms, and of extending or altering the present Chemical nomenclature, which is, indeed, allowed on all hands to be inadequate to the wants of Chemistry. These innovations have been as sparingly introduced as possible; but it was impossible without them to make the present state of the science intelligible to the reader. Various attempts have been made of late years on the Continent to introduce a new Chemical nomenclature. But I was unable to avail myself of any of these that I have seen, because they are all quite unsuitable to the idiom of our language. I regret, however, that I did not see the improvements in nomenclature proposed by Mr. Lunn, in the Article CHEMISTRY, in the Encyclo-

pædia Metropolitana, till it was too late to avail myself of them. Several of them are judicious. But before I saw them I had already introduced my own nomenclature into the work, and of course could not afterwards deviate from it.

There is one alteration in the present nomenclature which I regret I did not make, and which I think is still requisite in order to prevent ambiguity. In naming the sulphur acid salts, I have prefixed the syllables *sulpho* to the acid base with which the sulphur is united, making it terminate in *ate* or *ite*, precisely as is done with the oxygen acid salts. Thus, *sulpho-hydrate of sodium* is a salt composed of

> 1 atom sulphide of hydrogen,
> 1 atom sulphuret of sodium.

In the same way, *sulpho-arseniate of potassium* is a compound of

> 1 atom sulphide of arsenic,
> 1 atom sulphuret of potassium.

In short, the syllables *sulpho* prefixed, always indicate a sulphur salt. But there are two oxygen acids, which contain a modification of sulphuric acid, and which have been named by their respective discoverers, *sulpho-vinic acid*, *sulpho-naphthalic acid*. Of course, the salts which they form will be called *sulpho-vinates*, and *sulpho-naphthalates*. Here the syllables *sulpho* occur in salts containing an oxygen acid. To avoid this ambiguity, it would be requisite to change sulpho-vinic and sulpho-naphthalic, into *thio-vinic* and *thio-naphthalic*, substituting the Greek term for sulphur (theios), instead of the Latin, preserving the affix *sulpho* to denote the *sulphur salts*.

I have, on the authority of MM. Henry and Garot, given an account of an acid extracted by them from the seeds of white mustard, under the name of *sinapic acid*. From the subsequent researches on this subject by Henry, Pelouze, Boutron, and Robiquet,* it appears that this substance is not an acid, but a body which has been distinguished by the name *sinapisine*. I have thought it unnecessary to introduce this new view of the subject into the Appendix, because the substance *sinapisine* will come under our review hereafter, while treating of *vegetable* substances.

* See Journal de Pharmacie, xvii. 267, 271, 279.

The account of the salts in the second volume having extended to a greater length than was anticipated, swelled that volume much beyond the size of the first.   To make up in some measure for this, it was thought right to place the Appendix and Index at the end of the first volume, instead of the second.

GLASGOW, 1st *August,* 1831.

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OF VOLUME FIRST.

INTRODUCTION.

THE object of Chemistry, as the science is at present understood, is to determine the constituents of bodies and the laws which regulate the combinations and separations of the elementary particles of matter. All substances are either *simple* or *compound*. In simple bodies all the ultimate particles of which they are composed possess precisely the same properties; but from compound bodies at least *two* distinct kinds of particles may be extracted possessed each of a set of properties peculiarly its own. Thus all the particles which we can extract from a piece of pure iron possess exactly the same properties. Their colour is iron grey, their specific gravity about 7·8, they are soluble with effervescence in sulphuric acid, forming a light green solution having a sweetish and astringent taste, capable of striking a blue with prussiate of potash, and a black with infusion of nut galls. Iron then, as far as our chemical examination of it is capable of going, is a simple substance. The same observation applies to gold, to silver, and to the diamond.

But *saltpetre* is a compound substance, for by processes to be afterwards explained, we can extract from it two sets of particles, having each a set of properties peculiarly its own. These are *nitric acid* and *potash*. Nitric acid has a peculiar smell, an exceedingly sour taste, reddens vegetable blues, and corrodes and destroys the texture of animal and vegetable substances. When diluted with water it readily dissolves lead, copper, mercury, silver, and many other metals, but does not affect gold or platinum. Potash, on the contrary, is a white substance destitute of smell, but having a hot burning taste, and readily corroding any part of the living body to which it is applied. It converts vegetable blues to green, readily dissolves in water, and readily combines with the different acids, forming salts endowed each with peculiar properties. Thus saltpetre is a compound of nitric acid and potash.

Even nitric acid itself can be resolved into two kinds of matter, endowed each with different properties. These are *azote* and *oxygen;* both gases, destitute of smell and invisible and tasteless like common air. But oxygen is heavier than

azote in the proportion of 8 to 7. When a burning body is plunged into oxygen gas it continues to burn with additional splendour; but when plunged into azotic gas it is extinguished. Animals can breathe oxygen gas without inconvenience; but any attempt to breathe azotic gas, if persisted in would be attended with suffocation. Thus nitric acid is a compound of *azote* and *oxygen.* In like manner potash is a compound of oxygen, and a metal to which the name of potassium has been given. It is white like silver, lighter than water, and so combustible that when thrown upon water it immediately catches fire, and burns with a red coloured flame.

Thus saltpetre is a doubly compound body, being composed of *nitric acid* and *potash :* each of which constituents is also a compound, the former of *azote* and *oxygen*, the latter of *potassium* and *oxygen.* We can therefore extract from saltpetre three distinct substances, namely oxygen, azote, and potassium. These three substances cannot be resolved into any other kinds of matter; as far therefore as our knowledge of their constitution goes, they are simple bodies.

All (or almost all) the substances found upon the globe of the earth have been subjected to chemical investigation, with a view to determine which of them are simple, and which compound, and of what constituents the compound bodies consist. The result has been that all the animal and vegetable substances without exception, and by far the greatest number of mineral bodies, are compounds. The simple bodies, of which these compounds are composed, have been carefully examined and their number ascertained. The simple bodies at present known amount to 53: their names are as follows.

1 Oxygen	13 Selenium	25 Lithium
2 Chlorine	14 Arsenic	26 Calcium
3 Bromine	15 Antimony	27 Magnesium
4 Iodine	16 Tellurium	28 Barium
5 Fluorine	17 Chromium	29 Strontium
———————	18 Uranium	30 Aluminum
6 Hydrogen	19 Molybdenum	31 Glucinum
7 Azote	20 Tungsten	32 Yttrium
8 Carbon	21 Titanium	33 Zirconium
9 Boron	22 Columbium	34 Thorinum
10 Silicon	———————	35 Iron
11 Phosphorus	23 Potassium	36 Manganese
12 Sulphur	24 Sodium	37 Nickel

38 Cobalt	44 Bismuth	49 Platinum
39 Cerium	45 Copper	50 Palladium
40 Zinc	46 Mercury	51 Rhodium
41 Cadmium	47 Silver	52 Iridium
42 Lead	48 Gold	53 Osmium.
43 Tin		

Of these 53 bodies all the substances of nature hitherto examined are composed. The greater number of them are confined to the mineral kingdom. Animal and vegetable bodies are composed of a comparatively small number of simple substances, which, however, from the almost infinite variety in their proportions, give origin to the vast number of bodies which are obtained from the animal, and more especially from the vegetable kingdom.

If we were acquainted with the weight, the size, and the shape of the ultimate particles of these simple bodies, and with the laws which regulate their combinations with each other, the science of chemistry would be in the same state as Astronomy and Mechanics. But unfortunately this is far from being the case. Some little progress has been made in these investigations of late years, and we seem at least to be at last, on the road which may ultimately lead to a knowledge of the laws which regulate chemical combinations. But as yet nothing can be considered as definitely fixed or established. Every thing is little better than conjectural. Before proceeding to give an account of the simple bodies, and of the compounds which they form, it will be worth while to lay before the reader the present state of our knowledge respecting the laws which regulate the combinations of bodies with each other. This will constitute the subject of this introduction.

Ultimate particles of bodies, are

The opinion at present entertained by Chemists in general, is, that *simple substances* are aggregates of very minute particles, incapable of farther diminution, and therefore called atoms.* This opinion had been adopted by some of the ancient philosophers, Epicurus for example : but about the beginning of the eighteenth century, the prevalent belief was, that every kind of matter is capable of infinite division. This subject was treated by Dr. Keill in his introduction to Natural Philosophy, at considerable length, in his third, fourth, and fifth lectures,

Atoms.

* From the Greek particle α, and the verb τεμνειν, to cut. The word means literally, *incapable of being cut or divided.*

where those who are interested in such discussions will find the notions generally entertained at that time on the subject, the mode of answering the objections, and many curious calculations upon the infinite subtilty of matter.

What chiefly-induced modern chemists to adopt the notion that simple bodies consist of a congeries of atoms, was the observation, that they always combine with each other in definite proportions. For example, iron and sulphur combine in two proportions, and form two sulphurets; the first is a compound of 3·5 iron + 2 sulphur, and the second of 3·5 iron + 4 sulphur. Mr. Dalton, who first drew the attention of chemists to this circumstance, explained it by supposing that bodies are composed of atoms, endowed each with a peculiar weight; that it is these atoms which unite with each other chemically; that the weight of an atom of iron is 3·5, and that of an atom of sulphur 2. The first sulphuret therefore is a compound of 1 atom iron, and 1 atom sulphur. The second of 1 atom iron, and 2 atoms sulphur.

Always unite in definite proportions.

This explanation, in itself very plausible, has been strengthened by some other circumstances.

Atmosphere confined to the earth. Thence elasticity has a limit.

From the law of the elasticity which prevails in the earth's atmosphere, we know the degrees of rarity corresponding to different elevations from the surface. And if we admit that air has been rarefied so as to sustain only $\frac{1}{100}$ of an inch of barometrical pressure, we are entitled to infer that it extends to the height of 40 miles, with properties yet unimpaired by extreme rarefaction. If matter be infinitely divisible, the extent of the atmosphere must be equally infinite. But if air consist of ultimate atoms, no longer divisable, then must the expansion of the medium composed of them cease at that distance where the force of gravity downwards upon a single particle, is equal to the resisting force arising from the repulsive force of the medium.

If the air be composed of indivisible atoms, our atmosphere may be conceived to be a medium of finite extent, and may be peculiar to our planet. But if we adopt the hypothesis of the infinite divisibility of matter, we must suppose the same kind of matter to pervade all space, where it would not be in equilibrio, unless the sun, the moon, and all the planets possess their respective shares of it condensed around them; in degrees depending on the force of their respective attractions.

It is obvious that the atmosphere of the moon, supposing it to have any, could not be perceived by us. For since the den-

sity of an atmosphere of infinite divisibility at her surface would depend upon the force of her gravitation at that point, it would not be greater than that of our atmosphere is, when the earth's attraction is equal to that of the moon at her surface. Now, this takes place at about 5000 miles from the earth's surface, a height at which our atmosphere, supposing it to extend so far, would be quite insensible.

But since Jupiter is fully 309 times greater than the earth, the distance at which his action is equal to gravity, must be as $\sqrt{309}$, or about 17·6 times the earth's radius. And since his diameter is nearly 11 times greater than that of the earth, $\frac{17·6}{11} = 1·6$ times his own radius will be the distance from his centre, at which an atmosphere equal to our own, should occasion a refraction exceeding one degree. To the 4th satellite this distance would subtend an angle of about 3° 37', so that an increase of density to $3\frac{1}{2}$ times our common atmosphere, would be more than sufficient to render the 4th satellite visible to us when behind the centre of the planet, and consequently to make it appear on both sides at the same time. It is needless to say that this does not happen; and that the approach of the satellites, instead of being retarded by refraction, is regular till they appear in actual contact— showing that there is not that extent of atmosphere which Jupiter should attract to himself, from an infinitely divisible medium filling space.

If the mass of the sun be considered as 330,000 to that of the earth, the distance at which his force is equal to gravitation, will be $\sqrt{330,000}$ or about 575 times the earth's radius. And if his radius be 111·5 times that of the earth, then this distance will be $\frac{575}{111·5} = 5·15$ times the sun's radius. But Dr. Wollaston has shown by the phenomena attending the passage of Venus very near the sun on the 23d May, 1821, that the sun has no sensible atmosphere. For the apparent and calcu- lated place of that planet were the same when the planet was only 53' 15" from the sun's centre. M. Vidal of Montpellier, observed Venus on the 30th May, 1805, when her distance from the centre of the sun was about 46' of space, and the apparent and calculated positions of that planet corresponded. These observations leave no doubt that the sun has no sensi- ble atmosphere, and of course are inconsistent with the notion of the infinite divisibility of the matter of our atmosphere.*

* Wollaston; Phil. Trans. 1822, p. 89.

The conversion of solid and fluid substances into vapour is occasioned by the accumulation of heat in them, which by its elasticity overcomes the action of gravitation, and of cohesive attractions, and causes the particles to separate indefinitely, from each other. But if the ultimate particles of bodies be atoms, incapable of farther division or diminution, it is obvious that there must be a limit to vaporization; and that no vapour will be formed whenever the action of gravitation or cohesion or both is greater than that of heat. ' This has been very well illustrated by Mr. Faraday in his paper on the existence of a limit to vaporization.* It may be worth while to mention a few of the most remarkable illustrations of the truth of this opinion.

When some clean mercury is put into the bottom of a clean dry bottle, a piece of gold leaf attached to the under part of the stopper by which it is closed, and the whole left for some months at a temperature between 60° and 80°, the gold leaf will be found whitened by amalgamation, in consequence of the vapour which rises from the mercury beneath. Mr. Faraday tried this process in the winter of 1824–5; but could not succeed. Showing that the elasticity of the vapour of mercury at that cold temperature was less than the force of gravity upon it, and that consequently the mercury at that time was fixed.

Davy, in his experiments on the electrical phenomena exhibited *in vacuo*, found that when the temperature of the vacuum above mercury was lowered to 20°, no farther diminution took place, though the temperature was still farther lowered, even as far as —20°. The reason doubtless was, that at 20° mercury ceased even in vacuo to give out vapour.

Concentrated sulphuric acid boils at a temperature rather higher than 600°. Signor Bellani placed a thin plate of zinc at the upper part of a closed bottle, at the bottom of which was some sulphuric acid. No action took place in two years, the zinc remaining as bright as at first; showing that none of the acid is converted into vapour at common temperatures.

Thus the phenomena of evaporation, as well as the finite extent of our atmosphere, all tend to prove that matter is not infinitely divisible, but that its ultimate particles consist of atoms incapable of any further division or diminution. Let us see how far our knowledge extends relative to these ultimate atoms.

* Phil. Trans. 1826, p. 484.

1. The size of these ultimate atoms is minute to a degree, of which our limited imaginations can form no conception. A few illustrations will render this sufficiently evident.

Gold leaf is formed by beating fine gold between folds of parchment and vellum, and finally between prepared ox-gut, known by the name of gold beater's leaf. And it is beaten so thin, that Mr. Boyle found that 50·7 square inches of it weighed only one grain. Now, the 1000th part of a linear inch is easily visible through a common pocket glass. A square inch therefore is divisible into a million of parts, visible through a common microscope. Hence it follows that when gold is reduced to the thinness of gold leaf, $\frac{1}{50,700,000}$th of a grain of it may be distinguished by the eye. But the gold that covers silver wire is much thinner than gold leaf. Reaumur has shown that 1 grain of gold, of the thinness which it is upon gilt silver wire, will cover an area of 1400 square inches. It is plain therefore, that $\frac{1}{1,400,000,000}$th of a grain of gold may be seen through a common glass. But small as this particle is, we have no reason for believing that it does not constitute a considerable number of atoms.*

I dissolved 1 grain of dry nitrate of lead in 500,000 grains of water, and after having agitated the solution passed through it a current of sulphuretted hydrogen gas. The whole liquid became sensibly discoloured. Now, we may consider a grain of water as being about equal to a drop of that liquid. And a drop may be easily so spread out as to cover a square inch of surface. And under an ordinary microscope the $\frac{1}{1,000,000}$ of a square inch may be distinguished by the eye. The water therefore could be divided into 500,000,000,000 parts, every one of which, contained some lead united to sulphur. But the lead in a grain of nitrate of lead weighs only 0·62 gr. It is obvious therefore, that an atom of lead cannot weigh more than $\frac{1}{310,000,000,000}$th of a grain. While the atom of sulphur (for the lead was in combination with sulphur, which rendered it visible) cannot weigh more than $\frac{1}{2013,000,000,000}$ of a grain.

The size of these very minute quantities of matter might easily be computed; but it would be so small as to render it impossible for us to form any adequate estimate of it. For example, the bulk of the portion of lead which may be ren-

* Those who are curious to see a minute account of the mode of making gold leaf, and gilt wire, will find ample information by consulting Reaumur. Mem. Paris, 1713. p. 199. And Lewis's Philosophical Commerce, p. 44.

dered visible by the process above described, would be only $\frac{1}{888,492,000,000,000}$th of a cubic inch.

2. But notwithstanding the extreme minuteness of the size of the ultimate atoms of bodies, chemists have succeeded in determining that each of them has a specific weight, and in fixing the ratios of their respective weights with a considerable approximation to accuracy. The method of proceeding has been to determine when two bodies unite with each other, the weight of each which enters into the combination. For as only the ultimate atoms of bodies combine with each other, it is clear that the weight of each constituent of the compound will be in the ratio of the weight of the ultimate particles, or atoms of the respective bodies. When bodies unite only in one proportion, it is natural to infer that the compound consists ultimately of one atom of one body, united to one atom of the other. Thus, lead and sulphur are usually found combined in one proportion, constituting galena or common sulphuret of lead. This compound consists of 13 parts, by weight of lead united to 2 of sulphur. Hence, it is natural to infer that the weight of an atom of lead is to that of an atom of sulphur, as 13 to 2. In like manner there is only one sulphuret of bismuth known, composed of 9 parts by weight of bismuth, and 2 of sulphur. From this we may infer that the atom of bismuth is to the atom of sulphur as 9 to 2. Now 2 representing the weight of the atom of sulphur in both compounds, it is clear that the ratio of the atom of lead to the atom of bismuth must be that of 13 to 9.

Having thus determined the atomic weight of sulphur to be 2, we may consider the compounds of sulphur and oxygen, which are no fewer than 5. The names and constituents (by weight) of these respective compounds are as follows.

	Sulphur.		Oxygen.
Subsulphurous acid	2	+	1
Hyposulphurous acid	4	+	1
Sulphurous acid	2	+	2
Sulphuric acid	2	+	3
Hyposulphuric acid	4	+	5

If 2 denote the weight of an atom of sulphur, it is obvious that hyposulphurous acid and hyposulphuric acid contain each 2 atoms of sulphur. There can be only 1 atom of oxygen in hyposulphurous and subsulphurous acids. Sulphurous acid

contains 2 atoms of oxygen, and sulphuric acid 3 atoms of oxygen, combined each with one atom of sulphur. Hyposulphuric acid is a compound of 2 atoms of sulphur, and 5 atoms of oxygen, or it is the same thing as if it consisted of a particle of sulphurous, and a particle of sulphuric acid united together. Thus it appears that if 2 denote the weight of an atom of sulphur, 1 will denote the weight of an atom of oxygen.

In many cases it is not easy to fix upon the true number denoting the atomic weight of a body. We can always infer that the weight of one body that enters into combination with another, either denotes the atomic weight of the body, or at least a multiple or submultiple of that weight; but, in some cases it may be very difficult to determine which of the three. Thus, for example, we have two compounds of mercury and oxygen, the constituents of which by weight are as follows.

Difficult to determine the true weight.

	Mercury.		Oxygen.
Black oxide	25	+	1
Red oxide	25	+	2

We might consider the atom of mercury to be 25. On that supposition the black oxide would be a compound of 1 atom mercury + 1 atom oxygen, and the red oxide of 1 atom mercury + 2 atoms oxygen.

But we might also consider the atom of mercury as only 12·5 or the half of 25. In that case the red oxide would be a compound of one atom of mercury, and one atom of oxygen; and the black oxide of 2 atoms of mercury, and one atom of oxygen. There is nothing in these compounds that can determine which of these views is the right one. Both oxides are capable of combining with acids, and of forming salts. The red oxide is the most permanent, and intimate combination; but the black is always first formed when we attempt to combine mercury with oxygen. In such cases as this we are left to conjecture or analogy to assist us in deciding what number should be taken to denote the true atomic weight of the body. We see that the atom of mercury weighs either 25 or the half of 25; but which of the two it might in the present state of our knowledge be impossible to determine. In such a case we may be allowed to refer to analogy, to enable us to decide the point. It was first observed by Dulong and Petit, that when the atomic weight of a body is multiplied into its specific heat

the product is a constant quantity. And I have shown in my treatise on Heat that this product is always 0·376. There•fore, if we divide 0·376 by the number denoting the specific heat of mercury, the quotient should be the atomic weight of that body. But the specific heat of mercury is 0·03, and $\frac{\cdot 376}{0\cdot 03} = 12\cdot 52$. This circumstance furnishes a reason for considering the true atomic weight of mercury to be 12·5.

In like manner we have two combinations of copper and oxygen, the constituents of which are as follows.

	Copper.		Oxygen.
Red oxide of copper	8	+	1
Black oxide	8	+	2

We might consider the red oxide as a compound of 1 atom copper, and 1 atom oxgen, and the black oxide as a compound of 1 atom copper, and 2 atoms oxygen. In that case the atom of copper would weigh 8.

But we might represent the constituents of these oxides also, thus—

	Copper.		Oxygen.
Red oxide	8	+	1
Black oxide	4	+	1

According to this view of the compositions, the black oxide is a compound of one atom copper, and 1 atom oxygen; and the red oxide of 2 atoms copper, and 1 atom oxygen, and the atomic weight of copper would be 4. Thus we are left uncertain whether the atom of copper be 4 or 8.

If we examine the nature of these oxides in order to assist our views, we find that the black oxide is the most intimate compound, resembling in this circumstance the red oxide of mercury. We find that it constitutes the basis of all the cupreous salts, and that if its atomic weight be reckoned 5, the salts of copper are compounds of one atom acid + one atom base. But if we make its atomic weight 10, all the cupreous salts contain 2 atoms of acid united with one atom of base,—a peculiarity which would distinguish them from all the other genera of salts. Finally the specific heat of copper has been deter-mined to be 0·0949. Now, if we divide 0·376 by 0·0949 the quotient is 3·962. All these circumstances seem to leave no ground for hesitation, in preferring 4 to 8, as the true atomic weight of copper. If the specific heat of copper were 0·094

then $\frac{.376}{.094} = 4$. Now the difference between 0·094 and 0·0949 is greatly within the limits of error to which the determination of the specific heat of a body is liable.

But there are some cases in which it is very difficult to decide what the true atomic weight of a body is, even when assisted by all the analogical considerations to which we can have recourse. Thus oxygen and hydrogen unite in two proportions forming two compounds, the constituents of which are as follows.

	Hydrogen.		Oxygen.
Water	0·125	+	1
Deutoxide of hydrogen	0·125	+	2

If we consider water as a compound of 1 atom oxygen, and 1 atom hydrogen, the weight of an atom of hydrogen will be 0·125, or the eighth part of the weight of an atom of oxygen. But we might view the constitution of these compounds in this way.

	Hydrogen.		Oxygen.
Water . .	0.125	+	1
Deutoxide of hydrogen	0·0625	+	1

The deutoxide of hydrogen, according to this view of the compounds, would consist of one atom of hydrogen, united to one atom of oxygen, and water of two atoms of hydrogen united to one atom of oxygen. Thus the atom of hydrogen may either weigh 0·125 or 0·0625, which is the half of the former number.

If we have recourse to analogy to guide us in this difficulty we find water is by far the most intimate of the two combinations, and that it is always formed when oxygen and hydrogen enter directly into combination. We find that water combines definitely with various bodies, both acid and alkaline; but without neutralizing their peculiar qualities. But that deutoxide of hydrogen enters into no known combination. These analogies lead to the inference that the atom of hydrogen weighs 0·125.

But oxygen and hydrogen when in a separate state are both gaseous; and if we suppose them to enter directly into combination, and form the two compounds, these compounds will be composed as follows.

	Oxygen.		Hydrogen.
Water . .	1 volume	+	2 volumes
Deutoxide of hydrogen	1	+	1

Now it is more simple to consider the compound of 1 volume of each constituent, as composed of an atom of each, than to

reckon 1 volume of oxygen, and 2 volumes of hydrogen, as equivalent each to an atom. This view of the subject would lead to the opinion that the atom of hydrogen weighs only 0·0625.

In this dilemma we may have recourse to the specific heat of hydrogen gas, which will give us data, from which the true atomic weight of hydrogen is most likely to be determined. According to the experiments of Delaroche and Berard, the specific heat of hydrogen gas referred to water is 3·2936. Now $\frac{0.376}{3.2936} = 0.114$—a number much nearer 0·125, than to 0·0625. The specific heat then naturally leads us to determine in favour of 0·125 as the true atomic weight of hydrogen.

The following table exhibits the atomic weights of the simple bodies determined from the best data with which I am acquainted.

Table of the weight of the atoms of bodies.

	Atomic Weight.		Atomic Weight.
Oxygen	1	Magnesium	1·5
Chlorine	4·5	Barium	8·5
Bromine	10	Strontium	5·5
Iodine	15·75	Aluminum	1·25
		Glucinum	2·25
Hydrogen	0·125	Yttrium	4·25
Azote	1·75	Zirconium	5
Carbon	0·75	Thorinum	7·5
Boron	1	Iron	3·5
Silicon	1	Manganese	3·5
Phosphorus	1·5	Nickel	3·25
Sulphur	2	Cobalt	3·25
Selenium	5	Cerium	6·25
Arsenic	4·75	Zinc	4·25
Antimony	5·5	Cadmium	7
Tellurium	4	Lead	13
Chromium	4	Tin	7·25
Uranium	26	Bismuth	9
Molybdenum	6	Copper	4
Tungsten	15·75	Mercury	12·5
Titanium	4	Silver	13·75
Columbium	18	Gold	25
		Platinum	12
Potassium	5	Palladium	6·75
Sodium	3	Rhodium	6·75
Lithium	0·75	Iridium	12·25
Calcium	2·5	Osmium	12·5

It is not unlikely that some of these numbers may be twice as high as they ought to be.

3. After determining the ratios which exist between the weights of the atoms of simple bodies, the next particular which deserves investigation, is the comparative size of these atoms. Their absolute bulk we have seen is small, to a degree that exceeds the utmost stretch of the imagination. But from the great differences which exist between the specific gravities of bodies, there is reason to suspect that considerable differences must exist between the relative sizes of the atoms.

Five of the simple bodies are gaseous. Now, if we were to admit that the same volume of every gas contained the same number of atoms, then the atomic weight of a gaseous body divided by its specific gravity, would give us the ratio of the volume. We have no reason for supposing that equal volumes of azote, hydrogen and chlorine, do not contain the same number of atoms each. But it is, obvious that if the weight of an atom of hydrogen be 0·125, or, in other words, if water be a compound of one atom of oxygen and one atom of hydrogen, (since that liquid is a compound of 1 volume of oxygen, and two volumes of hydrogen,) a volume of oxygen must contain twice as many atoms as a volume of hydrogen.

The specific gravities of these gases, referred to oxygen as unity, are as follows.

	Sp. gravity.	Atomic weights.
Oxygen	1	1
Hydrogen	0·0625	0·125
Azotic	0·875	1·75
Chlorine	3·25	4·5

Dividing these atomic weights by the corresponding specific gravities, we obtain for the volumes,

Oxygen	2
Hydrogen	2
Azote	2
Chlorine	2

The volumes of hydrogen, azote, and chlorine are all equal. That of oxygen would appear at first sight to be only half that of the others, or *unity*. But if we recollect that half a volume of it contains as many atoms as a whole volume of the other gases, it is obvious that we must consider its specific gravity

not 1, but only 0·5; and $\frac{1}{0\cdot5} = 2$. So that the volume of an atom of oxygen is of the same size as that of the other three.

With respect to solid and liquid bodies there is some uncertainty of the relative number of atoms contained in a given volume of each. We have no evidence that the number of atoms in the same volume of each is not the same; and that the intervals in these solid and liquid bodies not occupied by matter, does not depend upon the relative size of the atoms. But we can produce no evidence whatever in favour of that opinion. The following table exhibits the relative volumes of the atoms of different bodies determined by dividing the atomic weight of each body by its specific gravity.

	Volume of the atom.		Volume of the atom.
Carbon	1	Tungsten, Bismuth, Mercury }	4·25
Nickel, Cobalt }	1·75	Tin, Sulphur }	4·66
Manganese, Copper, Iron }	2	Selenium, Lead }	5·4
Platinum, Palladium }	2·6	Gold, Silver, Osmium }	6
Zinc	2.75	Oxygen, Hydrogen, Azote, Chlorine }	9·33
Rhodium, Tellurium, Chromium }	3	Uranium	13·5
Molybdenum	3·25	Columbium, Sodium }	14
Silica, Titanium }	3·5	Bromine	15·75
Cadmium	3·75	Iodine	24
Arsenic, Phosphorus, Antimony }	4	Potassium	27

From this table we see (if any confidence can be put in the mode of calculation,) that the size of the atoms of bodies differs considerably from each other—and that carbon has the smallest, and potassium the greatest bulk of all atoms hitherto determined.

The atoms of manganese, iron, and copper, have the same size; and it is just double that of carbon. So that nature appears to have succeeded in the difficult mathematical problem of doubling a cube. Phosphorus, arsenic, and antimony, have also the same size, and it is just double that of iron, and quadruple that of carbon.

Rhodium, tellurium, and chromium constitute another group,

whose atoms have the same volume. The size of gold, silver, and osmium, is twice as great as that of these bodies. The size of the simple gaseous atoms is a little more than thrice that of chromium.
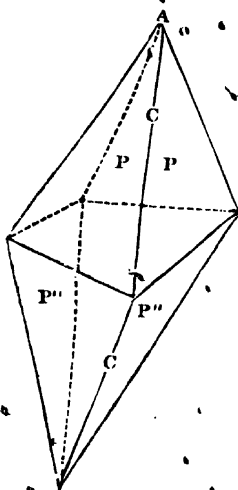
4. We have no means of forming any conclusions respecting Shape of atoms. the shape of the atoms of bodies which can be depended on. It has been concluded by some that the atoms of different bodies differ in their shape as well as in their weight and size. It has even been conjectured that the regular crystalline shape of bodies is owing to the regular shape of their atoms. And Hauy thought that the shape of the ultimate particles of bodies could be determined by cutting off slices from crystals parallel to all their faces, till the shape ceased to alter. Thus if we continue ever so long cutting off slices parallel to the faces of a cube or tetrahedron, what remains will always continue to be a cube or a tetrahedron; and if we dissect an octahedron ever so long, we shall always resolve it into octahedrons and tetrahedrons. But this could not give us the true shape, except on the supposition of the infinite divisibility of matter.

Were we to suppose all the atoms of matter to be spheres, Supposed spheres. it is plain that all the different crystalline shapes conceivable, might be formed by the aggregation of such spheres. Four of them placed in the angles of a tetrahedron, or eight of them at the corners of a very small cube supposed existing in space, would form the rudiments of the tetrahedron or cube. Six cubes applied to the respective faces of the cube, would form the octahedron. If the atoms of bodies were attached to each other without any intervening space between them, then some conclusions might be drawn from the shape of the crystals which they form; but as this is not the case, as the empty spaces existing in every body are probably considerable, and often certainly far exceed the portion of matter to which the shape is owing, it is clear that no legitimate consequences can be drawn, relative to the shape of the atoms of matter, from the figure which they produce when they cohere together constituting a sensible mass of matter. Accordingly, various opinions have been advanced upon this subject. Some suppose that the atoms of all bodies are spheres, or, at least rendered spherical by the atmosphere of heat collected around them. Dr. Wollaston was of opinion, that the regular figures of bodies could be best explained by the supposing the atoms

of bodies to be spheres, or sometimes oblong spheroids.* This also was the opinion of Dr. Hooke.
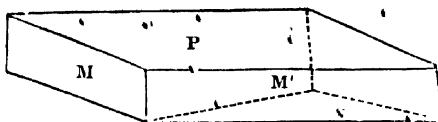
But there are some circumstances which seem scarcely consistent with this supposition, or at least do not seem easily explicable upon it, or deducible from it. The most important of these, is the fact, that several bodies are capable of crystallizing in two different and incompatible forms. M. Mitcherlich has shown that sulphur may be obtained crystallized in two different ways. 1. When it is dissolved in bisulphuret of carbon, and allowed to crystallize spontaneously, it forms an octahedron with a rhombic base, the face P inclining on P at an angle of 106° 20', and P on P'' at an angle of 143° 25'. 2. When a large quantity of sulphur is melted in a pot, and allowed to cool very slowly for four or five hours, if the thick crust formed on the surface be perforated, and the liquid sulphur be allowed to flow out by inverting the pot, large crystals of sulphur will be found lining the inside of the pot. The primary shape of these crystals, is an oblique prism with rhombic bases, in which the face M makes on M' an angle of 90° 32', and P on M an angle of 85° 54'½.†

Mitcherlich has not noticed the fact with regard to sulphur; but in general, when a substance assumes two different and incompatible shapes, the specific gravity and the hardness are found to differ as well as the shape. The most simple explanation of these two shapes of sulphur, is to admit that the atom of sulphur has a peculiar shape, and that when the atoms attach themselves to each other by certain faces, one of the primary forms is produced, and another primary form when they cohere by other faces. The shape of the atom may be such, that only two different kinds of faces exist in it. When the aggregation takes place by one set of faces, the intervals between the atoms may be smaller than when the other faces cohere. This would occasion a greater specific gravity and a greater degree of hardness. Sulphur is not the

* Phil. Trans. 1813, p. 51.
† Ann. de Chim et de Phys. xxviii. 264.

only substance which forms two different and incompatible primary forms. Several others are known to exist both among salts and minerals. I may mention the following as examples:

Carbonate of lime is found native crystallized in two distinct forms. 1. Calcareous spar which crystallizes in obtuse rhomboids, P forming on P' an angle of 105° 5'. 2. Arragonite, which has the form of a right rhombic prism, M on M' forming an angle of 116° 10'.

The specific gravity of calcareous spar, is 2·721, and that of arragonite 2·931. If the hardness of calcareous spar be reckoned 3, that of arragonite is 4.
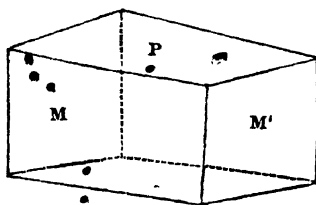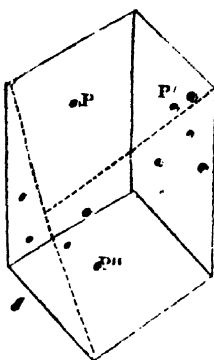
Bisulphuret of iron or common iron pyrites, is found crystallized in two forms: 1. Common iron pyrites has a cube, or perhaps a pentagonal dodecahedron for its primary form. 2. White or cockscomb pyrites has a right rhombic prism for its primary form, M or M' making an angle of 106°. The specific gravity of the former of these varieties, is 4·981, that of the other, 4·678.

The two minerals called *zoisite* and *meionite*, are each of them composed of the same constituents, being double salts consisting of two atoms of silicate of alumina, and one atom of silicate of lime; yet the former crystallizes in rhombic prisms, M on M' being 116° 30', and the latter in right prisms with square bases.

Idocrase agrees completely in composition with one of the varieties of garnet, both being double salts composed of one atom of silicate of alumina, and one atom of silicate of lime; yet the former crystallizes in right square prisms, and the latter in rhomboidal dodecahedrons.

Mitcherlich observed that the biphosphate of soda crystallizes sometimes in rectangular octahedrons, having usually a rectangular prism interposed between the pyramids, sometimes in right rhombic prisms, M on M' making an angle of 93° 54'.*

Sulphate of nickel crystallizes in two different forms. When the solution of the salt is neutral, the crystals formed are right rhombic prisms, M on M' forming an angle of about 91° 7'.

* Ann. de Chim. et de Phys. xix. 412 and 414.

When the solution contains an excess of acid, the crystals are right square prisms, exactly similar in shape to those of sulphate of magnesia.*

These 7 examples (and probably others might be adduced), are sufficient to show that the same substances, united in precisely the same proportions, are capable of crystallizing in two forms incompatible with each other. Now, if the atoms were all spherical or had all exactly the same form, as was conceived to be the case by Dr. Hooke and Dr. Wollaston, it is not easy to form a notion how these different forms could be assumed, or at least how they should be limited to two. Were we to suppose the shape of the atoms to be triangular prisms, or elongated cubes, or rhomboids, or rhomboidal prisms, some notion might be formed how the same atoms by uniting by their lateral or by their terminal faces, might form bodies of two different shapes, and differing likewise in their hardness and specific gravity.

But there is another remark of M. Mitcherlich which may ultimately lead to consequences of very great importance, and which accords much better with the notion that the ultimate figure of all atoms is the same, than that each has a peculiar figure of its own. He observed that phosphoric and arsenic acids form with the respective bases, crystals having either the same shape or deviating from each other only by a very small difference in the obliquity of the corresponding faces. Thus,

Biphosphate of potash, } crystallize in the very same octahe-
Binarseniate of potash, } drons and four-sided, rectangular prisms, terminated by four-sided pyramids.

Biphosphate of ammonia, } crystallize under the same forms,
Binarseniate of ammonia, } but with angles differing a little from the corresponding salts of potash.

Phosphate of soda, } crystallize both in right rhombic prisms,
Arseniate of soda, } M on M' being an angle of 67° 50' in both salts. All the secondary forms of both salts are similar.

Phosphate of ammonia, } crystallize also in right rhombic
Arseniate of ammonia, } prisms, M on M in the former being 84° 30', and in the latter 85° 54'. The secondary crystals in both salts are also similar.

* See the measurement of these crystals by Mr. Brooks; Annals of Philosophy (2d series), vi. 437. I have analyzed both varieties without finding any difference in their composition.

Biphosphate of barytes, }
Binarseniate of barytes, } crystallize under the same shape.

He found likewise that the following groups of salts crystal-lized each in the same shape, and were each identical in their composition—having in each similar crystal the same number of atoms of acid, base, and water.

Sulphate of manganese }
Sulphate of copper }

Sulphate of iron }
Sulphate of cobalt }

Sulphate of zinc
Sulphate of nickel }
Sulphate of magnesia. }

The following 13 double salts have also the same shape.

Ammonio—sulphate of copper
Ammonio—sulphate of manganese
Ammonio—sulphate of iron
Ammonio—sulphate of cobalt
Ammonio—sulphate of nickel
Ammonio—sulphate of zinc
Ammonio—sulphate of magnesia
Potash—sulphate of copper
Potash—sulphate of iron
Potash—sulphate of cobalt
Potash—sulphate of nickel
Potash—sulphate of zinc
Potash—sulphate of magnesia.

M. Mitcherlich farther observed that the crystalline forms of the salts of barytes, strontian, and lead, resemble each other. Thus the nitrate of each of these bodies is a regular octahe-dron. The sulphate of each is a right rhombic prism, in which M on M form the following angles:

Sulphate of barytes	101° 42′
————— strontian	104°
————— lead	103° 42′

The carbonates are also right rhombic prisms, having the following angles:

Carbonate of barytes	118° 30′
————— strontian	117° 32′
————— lead	117° 18′
Arragonite	116° 10′

* Kongl. Vetensk. Acad. Handl. 1821, p. 9. Ann. de Chim. et de Phys. xix. 350.

The carbonates of iron and manganese have also the same shape, an obtuse rhomboid; P on P in the former 107°, in the latter 107? 20'.

• The carbonates of magnesia, lime, and zinc, have likewise very nearly the same forms, being also obtuse rhomboids. The angle formed by P on P in carbonate of lime, is 105° 5', in carbonate of zinc, 107° 40', as determined by Dr. Wollaston. Carbonate of magnesia has never been measured; but the identity of form is inferred by Mitcherlich from the property which it has of crystallizing indefinitely with carbonate of lime.

Potash and ammonia, when combined with the same acid, give salts having the same shape, provided the ammoniacal salt contain two atoms of water.*

From these facts M. Mitcherlich drew as a conclusion, that when two acid bases combine with the same number of atoms of oxygen, and the resulting acids unite with another body in the same proportion, the resulting salts will have the same shape. He found by experiment that when salts can mix with each other, and crystallize jointly in any proportions, they have the same shape.

To substances (whether acids or bases,) which have the property of forming crystals of the same shape when they combine with other bodies, he has given the name of *isomorphous.* And he is of opinion that the atoms of such bodies have exactly the same shape. The following is a list of the different groups of isomorphous bodies which have been hitherto recognised.

List of iso-morphous bodies.

(1.) Lime, magnesia, manganese, oxide of zinc, black oxide of copper, protoxide of iron, protoxide of nickel, protoxide of cobalt.

(2.) Potash and ammonia.

(3.) Barytes, strontian, protoxide of lead.

(4.) Titanic acid, peroxide of tin.

(5.) Alumina, peroxide of iron, deutoxide of manganese, protoxide of chromium.

(6.) Phosphorus, arsenic, antimony.

(7.) Phosphoric acid, arsenic acid, antimonic acid.

(8.) Chlorine, bromine, iodine, and fluorine.

(9.) Sulphur, selenium.

This subject, pointing out the identity or similarity of the system of crystallization, which different bodies form when

* Ann de Chim. et de Phys. xiv. 172.

they enter into similar combinations, is undoubtedly highly worthy the attention of chemists; and the science lies under considerable obligations to M. Mitcherlich for the very curious facts which he has pointed out. But his general position that atoms of bodies having the same shape, form identical crystals, and that such atoms when they unite with the same number of atoms of oxygen, of base, and of water, form crystals of exactly the same shape, is belied by too many examples, which will readily occur to every chemist and mineralogist, to be admitted as an established fact.

We have no knowledge whatever of the shape of the ultimate atoms of bodies. Mitcherlich infers that phosphorus and arsenic have the same shape, because phosphoric acid and arsenic acid form with bases, crystals either identical, or at least differing from each other by very slight variations in the inclination of the respective faces. But it is not accurate reasoning, first, to infer the identity of form of the simple atoms, from the identity of the crystals formed by the compounds, and then to deduce the identity of form of the compounds from that of the simple atoms.

The only point which M. Mitcherlich has established, and it is a very important one, is, that when two salts have the same crystalline form, they may be mixed together and crystallized in any proportion whatever. M. Beudant made a set of experiments on the power which certain salts have of inducing their own form upon other salts, showing, that a few per cents of sulphate of iron when mixed with sulphate of zinc or sulphate of copper, cause these salts to crystallize in the shape of sulphate of iron.* Dr. Wollaston inferred from the transparency of these crystals, that they could not be mixtures of sulphate of iron with sulphate of zinc, or sulphate of copper, but chemical compounds of the two salts. Because these salts differ so much from each other in their respective powers, that mere mixtures of them could not be transparent.† Mitcherlich confirmed these conclusions of Wollaston by very decisive experiments. He mixed together sulphates of zinc and copper, and by crystallizing the mixed solutions, obtained crystals having the exact shape of sulphate of iron, though they did not contain a particle of this last salt. Sulphate of zinc crystallizes in square prisms, sulphate of copper in very oblique rhombic prisms, and sulphate of iron in right rhombic prisms

Salts having the same forms mix indiscriminately.

* Ann de Chim. et de Phys. iv. 72.
† Annals of Philosophy (1st Series), xi. 283.

of an intermediate obliquity, between that of sulphate of zinc and sulphate of copper. It was obvious that these crystals constituted a double salt, and accordingly it was found that the two salts existed in them in definite proportions.

Sulphates of copper and magnesia, sulphates of copper and nickel, sulphates of manganese and zinc, and sulphates of manganese and magnesia, all unite together, forming double salts having the form of the sulphate of iron. M. Mitcherlich has shown that the water of crystallization of these double salts differs from that of the two constituents, and is the same that exists in sulphate of iron.* Thus it has been proved, that the forms of the salts in Beudant's experiments, was not owing to the influence of sulphate of iron; but to the formation of double salts, the form of whose crystals happened to be the same as that of sulphate of iron.

Mitcherlich showed that the 13 double salts, enumerated in page 19 of this volume, may be mixed and crystallized in any proportion. Carbonates of lime, magnesia, and iron, are found native, mixed in an endless variety of proportions. This law serves to explain an apparent anomaly which occurs in mineralogy. Mineral species consist of simple or double salts united to each other in definite proportions. But there are some mineral species, whose varieties differ so much from each other in their chemical constitutions, that it has been impossible hitherto to establish their constitution upon satisfactory princi-

Varieties in the composi- tion of miner- als accounted for.

ples. The most remarkable of these minerals species, are the *garnet, pyroxene, amphibole,* and *chrysolite.*

The garnet is a well known mineral which crystallizes in rhomboidal dodecahedrons, and has usually a brownish red colour and a great degree of transparency and beauty. It consists essentially of a double anhydrous silicate, and might therefore be subdivided into three species, namely,

1. 1 atom silicate of alumina
    1 atom silicate of lime

2. 1 atom silicate of alumina
    1 atom silicate of iron

3. 1 atom silicate of lime
    1 atom silicate of iron.

These three salts,

Silicate of alumina
Silicate of lime
Silicate of iron,

* Ann. de Chim. et de Phys. xiv. 180.

are capable, when united, of crystallizing under the same shape. Hence, it happens, that we find minerals crystallizing like garnets containing these three salts in all proportions, or destitute of one of them, and containing the other two only.

Silicate of alumina constitutes the mineral called bucholzite; silicate of lime has not been yet found in the mineral kingdom; but it is often met with among the scoriæ of iron refineries, and frequently crystallized. Silicate of iron constitutes one of the varieties of the mineral called chrysolite or peridot, and is often met in the scoriæ of copper works. Thus the garnet is a compound of bucholzite and silicate of lime, or of chrysolite and bucholzite, or of silicate of lime and chrysolite. And the reason of the great variety which exists in its constitution, is, that these double salts, having each the same form, are capable of being mixed in any proportion, without altering the state of the crystallization or the form of the crystal.

Pyroxene is usually a double salt consisting of two bisilicates, which are either of the following:

<div style="text-align:center">

Bisilicate of lime,

Bisilicate of magnesia,

Bisilicate of iron.

</div>

Mitcherlich has observed crystals having the form of pyroxene, in iron scoriæ, and composed entirely of bisilicate of iron.

Bisilicate of lime is the mineral usually called *table spar*.

Bisilicate of magnesia is the mineral called *picrosmine*.

Bisilicate of iron is *basalt*.

So that pyroxene may be composed of table spar, picrosmine and basalt, united in almost any proportions.

The constitution of amphibole and peridot, admits of the same explanation.

If we were to adopt the notion, that the atoms of all bodies are spheres, then the isomorphism noticed by Mitcherlich would admit of an easy explanation. It is obvious, that wherever the bulk of two atoms is the same, one might be substituted for the other without inducing any change in the form of the crystal, of which it is a constituent. Now, upon inspecting the table of the volume of atoms given in page 14 of this volume, it will be seen that arsenic, antimony, and phosphorus, have the same bulk. This accounts for the remarkable isomorphism pointed out in these bodies by Mitcherlich and Rose.*

We have not data to determine the volumes of barytes,

Isomorphism owing to the identity of volume.

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* Poggendorf's Annalen der Physick. xv. 451.

strontian, and oxide of lead. But we will probably find that they have not exactly the same bulk, but that they do not differ much in this respect. Indeed, I have no doubt that isomorphism depends upon the identity of volume, and that the existence of similar suites of crystals, differing a little in their angles, like those exhibited by the compounds of stron-tian and barytes, are owing to an approach to the same volume in the atoms, without actually reaching identity.

As to the isomorphisms of alumina, peroxide of iron, deut-oxide of manganese, and protoxide of chromium, it is inferred solely from double salts, containing each of these bases crystal-lizing in regular octahedrons; too slender a ground surely to warrant such a conclusion. For the diamond, sal ammoniac, arsenious acid, gold, red oxide of copper, and many other bodies, the isomorphism of which cannot be maintained, crys-tallize also in regular octahedrons.

Upon the whole, then, the preponderance of evidence is rather on the side of the spherical form of atoms. Though this opinion is attended with difficulties, which in the present state of our knowledge cannot be obviated.

However, even were we to admit that all simple atoms are spheres, it is plain that compound atoms could not be spherical. The particles of water and of muriatic acid must be cylinders, being composed of two equal spheres combined together. Protoxide of lead must be a truncated cone, being formed of two spheres, whose diameters are to each other nearly, as the numbers 2·1 and 1·75. Protoxides of iron and manganese, and black oxide of copper, must be also equal and similar cones, being composed each of two spheres, whose diameters are nearly as the numbers 1·3 and 2·1. It is not improbable that four of these cones may unite together and constitute a cylin-der, which may be the state in which these particles aggregate together and constitute crystals.

Phenomena of chemical unions. 5. The following are the circumstances which take place, when bodies unite chemically with each other.

I. Compound unlike its constituents. (1.) The properties and appearance of the compound differ very much from those of its constituents. Thus, there is no resemblance whatever between *water* and its two constituents, oxygen and hydrogen. *Saltpetre* is quite different from *nitric acid* and *potash*, of which it is composed. Its taste is cooling and bitter, while that of nitric acid is sour, and that of potash caustic and hot. It is not corrosive, and may even be taken in small quantities into the stomach with impunity, while both

nitric acid and potash are two of the most corrosive substances in nature. It produces no effect on vegetable blues; while nitric acid renders them *red*, and potash *green*.

(2.) Bodies (as has been already observed) unite with each other only in definite proportions, which may be represented by numbers.

(3.) When bodies combine chemically, the union is always accompanied by a change of temperature. Sometimes the temperature sinks, but in by far the greatest number of cases it rises. The increase of temperature is usually proportional to the rapidity with which the combination takes place. In many cases the combination is so rapid that combustion is induced. *3. Temperature changes*

(4.) When two substances unite chemically, the bulk of the compound is very seldom exactly the same as that of its constituents. In most cases the bulk diminishes, though in some instances it increases. *Bulk changes.*

When 100 cubic inches of absolute alcohol, (sp. gr. 0·796) are mixed with 100 cubic inches of water, the spirit formed instead of 200 cubic inches, measures only 195·8 cubic inches. When tin and copper are melted together, in order to make the metal of cannons, the bulk of the compound is rather more than $\frac{1}{15}$th less than that of the two metals before union. Brass, which is a compound of about 8 parts by weight of copper, and $4\frac{1}{4}$ of zinc, is about $\frac{1}{20}$th less bulky than its two constituents were before union.

When a volume of azotic gas unites with half a volume of oxygen gas into protoxide of azote, the bulk of the compound is only 1 volume. So that these two gases by uniting, diminish in volume one-third part. When charcoal is burnt in oxygen gas, the volume of the gas does not increase or diminish, but its weight increases from 1·1111 to 1·5277. So that 1·1111 of oxygen gas has combined with 0·4166 of charcoal, without any increase of volume. The condensation or diminution in bulk therefore is very considerable.

On the other hand, when copper and gold are melted together, the alloy is more bulky than the constituents were before their union. For example, when $916\frac{2}{3}$ cubic inches of gold, and $83\frac{1}{3}$ of copper are melted together, the compound, instead of occupying the space of only 1000 cubic inches, amounts to 1024 cubic inches, the bulk therefore has increased rather more than $\frac{1}{42}$d part.

When a volume of azotic and a volume of oxygen gas combine to form deutoxide of azote, the new compound is still a

gas, and occupies the space of two volumes; so that the two ingredients have combined without altering their former bulk. Yet we are sure that a combination has taken place; for deut-oxide of azote possesses quite different properties, from a mere mixture of equal volumes of oxygen and azote; though the specific gravity of such a mixture would be the same as that of deutoxide of azote. We cannot combine oxygen and azote directly with each other into deutoxide of azote. But we can combine directly a volume of hydrogen gas with a volume of chlorine gas into muriatic acid. The combination is instantaneous and accompanied with combustion; yet the bulk of the muriatic acid is precisely the same as that of the two constituents before their union. The same observation is true of hydriodic acid, which is a compound of equal volumes of hydrogen and iodine vapour united together without any change of bulk.

The compounds which the metals form with each other, have been hitherto but superficially examined. Yet some examples are known of two metals which may be smelted together without any alteration of volume, though at the same time they form a chemical union with each other. Thus, M. Kupfer has shown, that when one volume of lead and two volumes of tin are melted together, the bulk of the alloy is just three volumes, so that neither dilatation nor contraction have taken place.*

Chemical compounds cannot be decomposed mechanically. 6. When bodies are chemically united with each other, we cannot separate them again by filtration, or any mechanical method whatever. Heat sometimes enables us to produce a separation; but in the greater number of cases this expedient is quite unsuccessful. When a volatile substance is united to another which is more fixed, it cannot be again separated so easily by applying heat, as we might be led to expect from our knowledge of the difference between the volatility of the two constituents. Thus, sulphuric acid does not boil till it be heated above 600°, while water boils at 212°. But if we heat a mixture of sulphuric acid and water, we will be disappointed if we expect that the water can be driven off at 212°. We must raise the heat much higher, before the liquid begins to distil over. And what passes into the receiver is not pure water, but a compound of sulphuric acid and water. It is true indeed, that the acid remaining in the retort is more con-

* Ann. de Chim. et de Phys. xl.

centrated than the liquid which distils over. But after the specific gravity of the acid is raised as high as 1·847, (or when it consists of a combination of 5 acid and 1·125 water by weight,) all farther concentration by heat is at an end. Nothing more passes into the receiver, till the heat is raised to the boiling point of the acid, and then the whole comes over, containing the acid and water still united together.

Muriatic acid is a gas, and lime a fixed body, yet when muriatic acid and lime are united into chloride of calcium, no heat that we can apply will separate the two ingredients from each other. We may heat the salt to redness and fuse it to a liquid, but the volatile constituent cannot be separated from the fixed one.

Ammonia is a gaseous body, and nitric acid a liquid. When united they constitute the salt called *nitrate of ammonia*. No heat which we can apply will separate the ammonia from the nitric acid. When the salt is heated to 300° it melts, and at 450° it undergoes decomposition, being entirely converted into water and protoxide of azote ; all traces of both the original constituents of the salt entirely disappearing.

It is therefore impossible in the greater number of cases, to separate the different substances that have been combined, either by mechanical means or by the application of heat. But by multiplying experiments in the way of mixture, a discovery has been made which has been of infinite use to chemists, and has greatly enlarged their power over a great number of different compounds. It has been found, that the addition of some third body to a compound of two ingredients, which are strongly united together by chemical combination, will in many cases dispose them to separate from each other. The third body unites to one of the constituents of the compound, and sets the other constituent at liberty. Thus, if we add potash in the requisite quantity to a compound of sulphuric acid and water, it will combine with the acid and set the water at liberty. A heat of 212° will now cause the water to boil, and it may be distilled over completely, and almost as easily as if the sulphate of potash were not present.

If we dissolve the compound of muriatic acid and lime in water, and add the requisite quantity of potash to the solution, the whole of the lime will be thrown down, and if after separat‧ing it by the filter, we evaporate the solution, we obtain a salt composed of muriatic acid and potash, or what is now called chloride of potassium. If, instead of potash, we add the requi-

site quantity of sulphuric acid to the solution of chloride of calcium, the muriatic acid is disengaged and may be obtained in a separate state by distillation, while the lime and sulphuric acid remain united together in the state of sulphate of lime.

The whole art of chemistry consists in forming compounds by uniting different bodies with each other, and in again separating them by the addition of a third body. And he is the best and most skilful chemist, who knows what the third body is which is capable of producing the decompositions that he has in view.

These combinations and decompositions mechanically explained. 7. What is it that occasions these combinations when bodies are mixed with each other? and how is it that a third body properly chosen, is capable of putting an end to combinations apparently so firm?

When we attempt to explain any curious phenomenon, the method which we take, is to endeavour to show that it may be referred to some principle with which we are already acquainted. But the phenomena of chemistry bear so little resemblance to any thing else with which mankind were familiar, that we need not be surprised that the first attempts to explain them were very unsuccessful. When we are told that an ingenious mechanic has contrived to move an immense mass of rock by the force of one man only, we will not be greatly surprised, if we are at all acquainted with the powers of mechanism. We know the thing to be possible, and that the machine is merely a contrivance for increasing force at the expense of velocity. But when the same rock is moved by a chemist, it is by no means so easy to understand the operation. If we are told, for example, that he mixed a small quantity of saltpetre, charcoal, and sulphur together, laid this mixture under the rock, and having applied a spark of fire to it, the rock was instantly thrown up with great violence and velocity out of its place—we find nothing here that is reducible to the common laws of mechanism,—no contrivance for increasing the force at the expense of the velocity—we wonder, we are astonished; but we cannot explain.

It was not till after the time of Lord Bacon that chemistry began to be studied by men who were acquainted with other branches of science. The mechanical powers of bodies being the most familiar of any, mankind have a propensity to employ them in explaining the phenomena of nature. Bacon recommended this sort of reasoning in preference to the language which was common in his time among chemists, and Mr. Boyle

afterwards attempted to introduce it and to support it more fully. It was applied in consequence with so much boldness, and so little judgment as to disgust men of real discernment, and to incline them to the notion, that chemical facts could not be explained in a satisfactory manner, by reasoning from mechanical principles.

The paper of Lemery, junior, published in the *Memoirs of* *the French Academy* for 1711, entitled *Sur les precipitatium chimiques*, affords an excellent example of this kind of reasoning. Lemery was a man of great celebrity, and judging from the memoirs which he has left us, he was possessed of considerable merit. He was a member of the Academy of Sciences of Paris, one of the most celebrated scientific institutions in Europe, and his lucubrations on solution and precipitation were thought worthy of publication by that learned body, 24 years after the appearance of Newton's Principia, and 7 years after that of his Optics.

According to Lemery, a fluid which has the power of dissolving a solid body, abounds with sharp and pointed particles, having the forms of needles or wedges, which are agitated in the fluid with a rapid and confused intestine motion. The solid again, has pores of such sizes and shapes as are fitted to the pointed particles of the fluid; these pores are penetrated, and the solid in consequence torn asunder. The reason why potash precipitates marble from its solution in muriatic acid, is, according to Lemery, because its particles are porous and spongy, and by this configuration, and by a confused motion, they take hold of, and break the spiculæ of the acid which held the particles of the lime attached to them. Nitric acid dissolves iron and copper, but not gold, because the two former metals have wider and more numerous pores than gold.

But it is needless to dwell at any great length upon an explanation, which is not only quite gratuitous, but altogether inconsistent with itself, and founded on principles utterly inadequate to explain the phenomena which it undertakes to elucidate. If the pores of iron be wider than those of gold, because it is soluble in nitric acid, while gold is not acted on by that acid; then the pores of gold must be wider than those of iron, because it is dissolved with the greatest facility by mercury, though that metal will not touch iron. Silver dissolves in nitric acid and not gold; but in aqua regia gold dissolves with facility, while silver remains undissolved. We cannot conceive these supposed intestine motions of fluids,

which are utterly insensible, to continue for ever; they must of necessity stop one another, and the particles of the liquid must come to a state of rest. Yet muriatic acid though kept for ages in a state of rest, would dissolve marble with as much energy as at first. We know, too, that solid bodies are capable of acting upon and dissolving one another, though it is not conceivable that their particles should be in a state of motion. Thus, common salt and snow when mixed together, immediately begin to act upon and mutually to dissolve one another.

These attempts of Lemery and some other similar ones were utterly unsatisfactory—and indeed no chemical theory existed which connected chemistry with the other parts of science, till Newton published the second edition of his Optics, in the year 1717. To the end of this edition he subjoined thirty-one queries, the last of which relates to chemistry. In this query he lays open a view of chemical combination and decomposition, which is altogether his own, which is much more satisfactory, and which makes them appear much more conformable to the rest of natural phenomena than any that had been offered before.

Explanation of Newton.

Newton had already thirty years before explained the motions and connexion of the heavenly bodies with one another, by showing that they are retained in their orbits by the same power which determines a stone to fall to the ground—a power usually called *gravitation* or the attraction of gravitation. He conceived that there are other forces or principles of motion in nature, by which certain bodies act or appear to act at sensible distances on one another. This is evidently the case with the attractions and repulsions connected with electricity and magnetism; he suspected that there are still other forces whose sphere of action is still smaller, being confined to the ultimate particles or atoms of bodies—and so small indeed as to escape our senses. These actions or forces he considered as manifest in the attraction and cohesion of polished planes and metals, in what is called *capillary attraction*, and in the *inflection* and *deflection* of light as it passes near the edges of solid bodies.

He suspected that chemical combinations and decompositions depended upon powers somewhat resembling the others. He was of opinion that the ultimate particles or atoms of certain bodies attract each other with an unknown but enormous force, which begins to exert itself only at very minute distances. Hence when such bodies are mixed, the particles of each being

brought within the requisite distance, this force exerts itself and the bodies unite. The decompositions produced by the addition of a third body he ascribed to the superiority of the attraction of this third body for one of the constituents of the compound, in consequence of which it unites with that constituent and separates the other which was previously in combination. Thus muriatic acid dissolves marble, because the attractive force between the particles of the acid and those of lime is greater than the force by which the particles of the marble cohere together, and than the force which united the lime in the marble to the carbonic acid. They are therefore separated from each other, and a particle of lime uniting to every particle of muriatic acid, the whole lime, if the quantity of acid be sufficient, is equally diffused through the liquid. When potash is added the lime again falls down, because the potash has a greater attraction for the particles of the acid than the lime has; it therefore unites with the acid and separates the particles of lime, which being disengaged, obey the laws of gravity, and fall to the bottom of the vessel.

These views of Newton made their way into the science very slowly; but before the middle of the last century they seem to have been almost universally adopted. Chemists, however, instead of the term *attraction* employed by Newton, substituted *affinity*, first introduced into *Chemistry* by Dr. Hooke, and caught with avidity by the chemists on the Continent. By *chemical affinity* then is meant that unknown force which causes the ultimate particles of different bodies to unite together and to remain united. This term is in some respects preferable to *attraction*. Because this last term naturally suggests the idea that the united bodies are drawn nearer to each other than they were before their union, which is not always the case. For when hydrogen and chlorine unite to form muriatic acid they do not approach nearer each other than they were before their union; and when gold and copper are alloyed together the volume of the compound increases, so that the constituents appear to have receded farther from each other than before they united. *Affinity* indicating merely the power or the force which produces the union, seems well adapted for the purposes of science.

As soon as the Newtonian notions of affinity were adopted by chemists, they naturally concluded, that, when a compound *a b* was decomposed by the body *c*, which combined with *b*, disengaging *a*, this was because *c* had a stronger affinity for *b*

Affinity what.

than a had.   Decomposition therefore came to be considered as the measure of the strength of affinity.   Dr. Mayow of Oxford seems to have been the first who demonstrated that bodies follow fixed and constant laws in their action on each other.   He showed that volatile alkali is separated from all acids by the fixed alkalies, that nitric acid is disengaged from saltpetre by sulphuric acid, and that metals are precipitated from acids by potash.*

Tables of affinity.   In the year 1718, M. Geoffroy, senior, thought of arranging bodies in the order in which they separate each other from a given substance.†   Bodies thus arranged were considered as exhibiting the order of the affinity of the respective bodies for the substance with which they united; that body being placed highest which had the strongest affinity or was capable of displacing all the others.   The rest of the bodies were placed in the order of their affinity.

Geoffroy's tables were necessarily very imperfect.   The first great improvement of them was by Gellert, in his Metallurgic Chemistry, first published in 1751.   In 1761 a still more extensive table was given to the chemical world by M. Limbourg. Bergman's Dissertations on *Elective Attractions* (as he termed *affinity*) was first published in 1775 in the third volume of the Memoirs of the Royal Society of Upsala.   This work, afterwards republished by the author in 1783 in the third volume of his Opuscola, appears to have fixed the opinions of chemists in general to his own views of the subject.   According to him the affinity of each of the bodies a, b, c, d, &c. for x differs in intensity in such a manner that the intensity of the affinity of each may be expressed by numbers.   He was of opinion also that affinity is elective, in consequence of which if a have a greater affinity for x than b has, if we present a to the compound $b x$, x separates altogether from b and unites to a.   Thus barytes has a stronger affinity for sulphuric acid than potash has; therefore if barytes be mixed with a solution of sulphate of potash, the sulphuric acid will leave the potash and combine with the barytes.   He examined the alleged exceptions to this general law, and accounted for them with such plausibility as to remove the doubts that had hitherto hung over the subject. Bergman's table of affinities, constructed according to the plan of Geoffroy, was much more copious than any that had preceded

* Mayow de Sal nitro, p. 232.
† Mem. Paris, 1718, p. 202.

it, containing all the chemical substances at that time known. It consists of 59 columns. At the head of each of which is placed a chemical body, and the column is filled with the names of all the substances which unite with it, each in the order of its affinity. Each column is divided into two compartments by a black line. In the first is exhibited the affinities in the order of the decompositions when the substances are in solution. In the second compartment are exhibited the order of the decompositions when the substances are exposed to a strong heat, as for example by heating them to redness in a crucible. The first of these he called the affinities by the *wet way*, the second the affinities by the *dry way*.

Bergman's opinion that affinity is elective, and that the order of affinities is determined by decomposition, continued to be universally admitted by chemists till Berthollet published his Dissertation on Affinity, in the third volume of the Memoirs of the Institute, and his Essay on Chemical Statics in the year 1803. He considered affinity as an *attraction* existing between the bodies which combine, and an attraction probably similar to that which exists between the planetary bodies. But as those bodies which obey the impulse of affinity are at a very small distance from each other, the strength of their affinity depends not merely upon the quantity of matter which they contain, but likewise upon their shape. Affinity being an attraction, must always produce combination; and as the attraction is analogous to that of the planetary bodies, it follows as a consequence in Berthollet's opinion, that the affinity must increase with the mass of the acting body. Thus though barytes has a stronger affinity for sulphuric acid than potash; yet if we present a great quantity of potash to a small quantity of sulphate of barytes, the potash will separate a portion of the acid.

According to this new doctrine, affinity is not elective. A substance which has a stronger affinity is not capable of separating completely those which have a weaker affinity; or if this happens, some other cause intervenes. Instead of separating the weaker body, it divides with it the base to which that body was united; each combining with a part proportional to the strength of its affinity and the quantity present. This opinion is exactly the opposite of the old one. According to the former hypothesis, when sulphuric acid is dropped into nitre, it separates the whole of the nitric acid, and takes its place. According to Berthollet, each of the acids combines with a portion of the

Berthollet's explanation of affinity.

base of the nitre, and the portion which unites to each is proportional to the strength of affinity and the quantity of each acid employed.

. But it is a matter of fact that the addition of a third body frequently separates two substances previously united, the third body taking the place of one of the constituents, which is thereby separated altogether. Thus if sulphuric acid be dropped into nitrate of barytes, the barytes combines with it, leaving the nitric acid in a disengaged state, while the sulphate of barytes precipitates to the bottom. Or if potash be dropped into a solution of nitrate of lime, the lime precipitates to the bottom, and the alkali instead of it unites to the acid. These facts, and many others which will immediately occur to every chemist, appearing at first sight contrary to Berthollet's theory, it was necessary for him to reconcile them to it. According to him, whenever decomposition takes place it is owing either to the insolubility or the elasticity of the ingredient which separates. Sulphate of barytes being insoluble in water, while nitrate of barytes and nitric acid are soluble in that liquid, it must happen when the substances are mixed that the insoluble salt precipitates on account of its insolubility. It is the insolubility of lime that causes its precipitation when potash is dropped into nitrate of lime. Accordingly when potash is dropped into nitrate of soda, no precipitation whatever takes place, because both the potash and the soda are very soluble in water. But if we concentrate the solution sufficiently by evaporation, crystals of nitrate of potash will be deposited, because that salt is much less soluble in water than nitrate of soda. In like manner when nitric acid is poured upon carbonate of potash the carbonic acid is disengaged and flies off; because its elasticity causes it to separate from the liquid and assume the gaseous state, as soon as the nitric acid weakens the attraction by means of which it was attached to the potash.

Not satisfactory. The opinions which Berthollet endeavoured to establish were not only inconsistent with those of Bergman, but utterly subversive of the whole science of chemistry, if he could have established them. He maintained that a third body c, was not capable of disengaging a from b in consequence of any superiority of affinity; but in consequence of some other circumstance (as insolubility or volatility) totally unconnected with the strength of affinity; that the strength of affinity may in all cases be overcome by employing a sufficient quantity of another body,

though its affinity be weaker; and that bodies are capable of uniting with each other in any proportion whatever, except in so far as definite compounds may be occasioned by some other unconnected circumstance. On this last point a controversy was carried on between Berthollet and Proust. The latter of whom showed by innumerable proofs that all compounds are definite, and that no two bodies are capable of combining except in certain determinate proportions. The progress which chemistry has made since the time of this controversy leaves no doubt whatever upon the mind of any one that the views of Proust were correct, while those of Berthollet were completely erroneous.

Nor is it very clear that the opinion of Berthollet, that mass is capable of compensating for strength of affinity, is perfectly correct. Affinity acts only between the atoms of bodies, which are so exceedingly minute, that however strong the power may be it cannot begin to act till the atoms approach within a very small distance from each other. Were it possible for two atoms of b to approach as near a, as 1 atom of c can, then it is very probable that the joint action of the two atoms might be able to overcome the action of the single atom, c; though the affinity of c may be much stronger for a than that of a single atom of b. But the very circumstance that c when added to q b has the property of disengaging b, and of uniting with a in its place, renders it evident that there is something which prevents the possibility of b and c being at the same time at an equal distance from a. c not only attracts a; but it must at the same time repel b; and the decompositions and new combinations must be produced by these joint repulsions and attractions.

It is the explanation of the decomposition produced by the action of a third body that constitutes the weak part of Bergman's doctrine of elective attraction. If affinity be mere *attraction*, it is impossible to conceive any reason why the addition of c to a b should cause the separation of b from a. c ought to combine with a b, and form a triple compound a b c. To tell us that it is a law of nature, that only two bodies can combine with each other at once, is merely eluding the difficulty without obviating it. This was the part of Bergman's doctrine which Berthollet attacked with most success; but the structure. which he endeavoured to rear upon the ruins of Bergman's hypothesis was not more stable than that of his predecessor had been.

Sir Humphrey Davy, in his admirable paper on Galvanism, published in the Philosophical Transactions for 1807,* endeavoured to show that substances having an affinity for each other are in different states of electricity, the one plus and the other minus; that the more intensely these two different states exist in two bodies, the stronger is their affinity for each other, and that in order to decompose a compound, or to put an end to the union between its constituents, we have only to bring them into the same electrical state.† From these premises he drew as a conclusion that *chemical affinity* and *electrical attraction* are identical forces. The probability of this opinion has been strengthened by many observations on combination and decomposition. And M. Ampere has developed at considerable length the ingenious views which he has formed respecting the identity of electricity and chemical affinity. The electrical theory has been embraced by every chemist of eminence who has written on the subject since the appearance of Davy's paper, and seems at present to constitute an universally admitted opinion.

This electrical theory enables us to account for chemical decompositions by the action of a third body, in a more satisfactory way than could be done by Newton, or by Bergman, who followed up the Newtonian views, and without having recourse to the subtilties which Berthollet adopted, and which if correct would have put an end to definite compounds altogether.

Oxygen, chlorine, bromine, and iodine are always in a *negative* state, while the other simple bodies are positive. Hence the reason why these four bodies have a tendency to combine with all the others. Potassium is very strongly *positive*, while oxygen is equally strongly negative. Hence the strong affinity which exists between these two bodies, and the difficulty of decomposing them when they are united. If a current of chlorine gas be passed through hot potash (which is a compound of potassium and oxygen) the oxygen is disengaged in the state of gas, and the chlorine unites to the potassium in its place. This decomposition is brought about by the agency of two forces. Chlorine like oxygen is negative. It is there-

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* Entitled, *On Some Chemical Agencies of Electricity.*
† See an account of several of his experiments in my work on Heat and Electricity, p. 491.

fore attracted by the potassium and repelled by the oxygen. The heat acts partly perhaps by diminishing the cohesion which exists between the particles of potash; but chiefly by exalting the negative energy of chlorine. This energy when increased by heat is greater than the negative energy of oxygen. Hence its attraction for potassium must exceed that of oxygen for the same base. It therefore takes the place of the oxygen; and the mutual repulsion between chlorine and oxygen, together with the elasticity of the oxygen, is sufficient to cause that principle to fly off and make its escape.

The reason why many bodies require a red heat before they combine, and why when raised to that temperature they unite with great energy, does not appear, if we confine ourselves to the notions of affinity entertained by Bergman. But the electrical theory enables us to assign a reason for this effect of heat. Let us take the case of oxygen and hydrogen gases. The former of these bodies is negative and the latter positive. They have therefore a strong attraction; but this attraction is not sufficient to overcome the mutual elasticity of the two gases, occasioned probably by an atmosphere of heat surrounding the atoms of each. But a red heat exalts the electric energies of both so much, that they are enabled to overcome the resistance occasioned by the elasticity of the gases, and in consequence to combine together.

Thus the electrical theory of affinity holds out advantages over the old hypothesis, which will serve to explain the reason why it has been so generally adopted, and why it is at present so great a favourite with chemists. However, when we take a closer view of chemical combinations and decompositions, several difficulties present themselves of no ordinary weight. These difficulties will be best understood by taking a view of some of the most common cases of combination and decomposition with which chemists are familiar. We will at the same time have an opportunity of judging how far they can be obviated, and whether they be sufficient, as has been alleged by , some, to oblige us to reject the electrical explanation of affinity altogether.

It may be proper to observe in the first place, that Ampere, who has favoured the world with the most detailed view of the electric theory, considers every atom of matter as essentially and unchangeably either in a state of *positive* or *negative* electricity. The consequence of this state he thinks must be, that every atom is surrounded by an atmosphere of a contrary elec-

tricity. The atoms of hydrogen, for example, which are *positive*, are surrounded by an atmosphere of *negative* electricity, while the atoms of oxygen, which are *negative*, are surrounded with an atmosphere of *positive* electricity. The consequence of this state of things, he thinks, will be that when an atom of hydrogen approaches to an atom of oxygen, their two atmospheres in the first place neutralize each other. This combination of the two electricities produces heat and light. Hence, in his opinion, the origin of the combustion which so frequently accompanies rapid combinations.

This way of accounting for the heat and light evolved by rapid combinations has been long a favourite with men of science. It was long ago maintained by Ritter. It was likewise the opinion of Winterl; and more lately of Œrstedt. But in my work on Heat and Electricity I have stated a series of facts which seem altogether inconsistent with it, and which go far to prove that the electric spark is occasioned not by the union of the two electricities, but by the sudden condensation of the air or other elastic medium through which the electricity passes. When long sparks are drawn from a conductor, that part of the spark where the two electricities unite is always the faintest, a fact quite incompatible with the notion, that the spark is produced by their union. Indeed the spark is always brightest at its negative and positive extremities, showing clearly that it is not connected with the union of the electricities, but depends upon the action of the electricity on the air. No doubt, it is some difference in the way that the two fluids act on the atmosphere, that occasions the difference in the appearance of the sparks drawn from a negative and positive body.

The quantity of electricity in atoms not fixed. Neither can the position of Ampere, that every atom is essentially and unchangeably in a state of positive or negative electricity, though upon it the plausibility of the electric theory in a great measure depends, be admitted without considerable modifications. There is a strong affinity between sulphur and oxygen. They combine in various proportions, forming powerful acids. When these acids are decomposed by the galvanic battery, the oxygen attaches itself to the positive pole and the sulphur to the negative. Hence we are entitled to infer, that oxygen is *negative* and sulphur *positive*. But sulphur combines likewise with hydrogen and forms an acid; and when this acid is decomposed by galvanism the hydrogen is found to be *positive* and the sulphur *negative*.

Thus it appears that sulphur with respect to oxygen is *positive;* but with respect to hydrogen *negative.* Its state then is neither essentially positive nor negative, since it changes according to the substance with which it combines. The very same remark may be made of *selenium, arsenic, tellurium,* and even *carbon.* When these bodies combine with oxygen they are positive; but when they combine with hydrogen they are negative. Again chlorine and oxygen are capable of combining, and it appears when the compound is decomposed by galvanism, that the oxygen is *negative* and the chlorine *positive.* Both combine with calcium, and when the oxide and chloride of calcium are decomposed by galvanism, it appears that the oxygen and chlorine are both *negative* and the calcium *positive.* Now since oxygen with regard to chlorine is negative, surely we must admit that it is the most negative of the two. It ought therefore, according to the electric theory, to have a stronger affinity for calcium than chlorine has. Yet if we heat oxide of calcium, and pass a current of chlorine gas over it, the oxygen will be disengaged, and the chlorine will take its place. Here we have chlorine *positive* with regard to oxygen, and *negative* with regard to calcium. And we have a body which appears to be *less* negative displacing a body which is *more* negative than itself. How are these facts and many others of a similar nature to be explained?

If the two electricities consist of two distinct fluids, and if these fluids be inseparably connected with the atoms of bodies, so that every atom contains at all times and in all situations exactly the same quantity of negative or positive electricity, it is obviously impossible that a body can be positive with respect to one body and negative with respect to another. It must invariably preserve in all cases either its negative or its positive state. Now this is not the case with atoms in general. For with the exception of hydrogen, potassium, and perhaps one or two other alkaline bases, there are no bodies invariably *positive;* and except *oxygen* there is perhaps no body invariably *negative.* We must therefore conclude that the atoms of bodies do not contain each a specific quantity of electricity which is not capable of varying.

It is much more probable that both electricities exist in every atom; though in most cases one of the two fluids preponderates over the other, and that the fluids are not inseparably attached to the atoms; but capable of being increased or diminished according to the laws which bodies follow with regard to elec-

How a body may be both negative and positive.

tricity. Now taking this view of the subject, let us see whether the electric theory be not compatible with the atom of a body being in a different electrical state with regard to different bodies. In oxygen there is a great preponderance of negative electricity. It is negative with respect to every other body. Sulphur is negative with regard to most bodies; but it is obviously not so powerfully negative as oxygen. Let us suppose now an atom of sulphur to be placed within a very small distance of an atom of oxygen. We know that the two electricities will act on each other. The negative electricity of the oxygen atom will repel the negative electricity of the sulphur, and as the atom of oxygen is almost twice the size of an atom of sulphur, and contains a much greater quantity of negative electricity, it is evident that it will act with greater energy. A portion of the negative electricity of the sulphur will be driven off; while the positive electricity will accumulate in consequence of the attraction exercised on it by the negative electricity of the oxygen. Positive electricity will accumulate in it, and negative electricity will diminish. This will of course render it *positive*, though before the action of the oxygen on it, it had been negative. In consequence of these two different states, the two atoms combine, and the attraction between the two electricities will prevent any alteration in their state as long as they remain united. We may in this way easily conceive how an atom may be positive when it combines with one body, and negative when it combines with another.

As for the difficulty respecting chlorine, that though less negative than oxygen, it notwithstanding separates oxygen from calcium, it must be observed that this separation is not induced unless heat be applied; the reason probably is, that heat has a greater effect in exalting the electricity of chlorine than of oxygen. Hence though chlorine while cold is less negative than oxygen, it probably becomes more negative when strongly heated.

Why chlorine separates oxygen.

By this view of the subject, most of the difficulties may be obviated, and the electrical theory of electricity rendered at the same time much more conformable to the common phenomena of electricity and the laws which regulate the accumulation or diminution of electricity in bodies, than it would be if we considered every atom as endowed with an inseparable quantity of one or other of the two electricities.

With respect to the unknown link which unites the electricity to these atoms and keeps it united to them, we are quite

in the dark.   It is not an attraction similar to gravitation; for it is demonstrable that the electricity is deposited only on the surface of the atom, and that its quantity capable of accumulating, is proportional to the surface, and bears no relation whatever to the weight of the atoms.

The number of atoms of one body, capable of uniting to an atom of another body, is probably connected with the state of the electricity of both.   If the positive electricity of one atom be just neutralized by the negative electricity of another, we might expect that the two bodies would unite only in one proportion; or at least, that the compound consisting of one atom of each body would be the most stable.   But if one atom be twice as positive as another is negative, or *vice versa*, then we might expect that a compound consisting of one atom of one body and two atoms of the other, would be most stable.

Salts are composed of an acid united to an alkali usually atom to atom; and it is generally observed, that they are more difficult of decomposition than the acids or bases, constituting them when in an insulated state.   Thus, sulphuric acid is decomposable by a red heat; but sulphate of potash may be exposed to a red heat without undergoing any alteration. Oxide of silver is easily deprived of its oxygen by a moderate red heat; but phosphate of silver is capable of bearing a red heat without undergoing any alteration.   The reason of this increase of permanence, probably, is owing to the way in which the constituents combine.   The acid being composed of two constituents, one of which is positive and the other negative, may be represented thus, $+$ $-$;   The alkaline base being similarly composed may be represented by the same symbol, $-$ $+$.   Now, there can be little doubt that the acid and base when combined, will arrange themselves thus, *(margin: Why salts are more stable than their compounds.)*

$$+ \quad -$$
$$- \quad +$$

that is to say, the positive ingredient of the one will attach itself to the negative ingredient of the other.   Thus, every negative body will be placed between two positive, and every positive between two negative—a situation which ought to increase the firmness and steadiness of the compound.

The black oxide of manganese employed for obtaining oxygen and chlorine, is a compound of one atom of manganese and two atoms of oxygen.   When strong sulphuric acid is poured over this compound, one half of the oxygen of the oxide is disengaged and makes its escape in the gaseous state, *(margin: Why teroxide of manganese is reduced to protoxide by sulphuric acid.)*

while the sulphuric acid unites with the protoxide of manganese, and forms a sulphate of manganese. What is the reason of this disengagement of the oxygen? It may be observed in the first place, that manganese is the most positive of all the metals. Hence, it is capable of uniting with and condensing into a solid, no fewer than three atoms of oxygen, although the size of the atom of oxygen is more than four times as great as that of the atom of manganese. When manganese is united with only one atom of oxygen, it still retains its positive nature so strongly as to possess powerful alkaline qualities, and to be capable of uniting with and neutralizing the different acids. But when it has combined with three atoms of oxygen, it has become negative, and possesses the characters of an acid. We see, therefore, that three atoms of oxygen are more than capable of neutralizing one atom of manganese; but the black oxide, which is a compound of one atom of metal and two atoms of oxygen, does not appear capable of uniting either with acids or bases; it is therefore a neutral compound. But the second atom of oxygen cannot be retained by the manganese with the same force as the first atom.

Sulphuric acid is a compound of one atom of sulphur and three atoms of oxygen. The oxygen is obviously not neutralized by the sulphur, for the compound possesses powerful acid properties. Here then we have two bodies brought into contact, containing both oxygen in considerable quantity and not neutralized by the bases with which it is combined. The oxygen in both being highly negative, it is obvious that the atoms of it must repel each other. The volume of the sulphur atom being much larger than that of the atom of manganese, acts with most energy in retaining its oxygen. The manganese combined with two atoms of oxygen is a neutral compound, while the protoxide is an alkaline body; hence, the protoxide of manganese (being positive) will be attracted by the sulphuric acid, while the second atom of oxygen united to the manganese will be repelled by the oxygen in the acid, and even by the other atom of oxygen united to the manganese; it will therefore be expelled and the sulphate of manganese formed.

But not by nitric acid. It may be asked why the same decomposition of black oxide of manganese does not take place when nitric acid is poured over it. The reason seems to be, that the azote, the atom of which is of the same size with that of oxygen, more completely neutralizes the oxygen in the nitric acid; it does

not therefore act with so much energy in repelling the oxygen united with the manganese ; but that it acts is evident, because when a little sugar is added to the mixture, the second atom of oxygen in the oxide combines with carbon, and the nitric acid immediately forms a nitrate of manganese.

The curious phenomenon observed by Thenard when metallic oxides are placed in contact with deutoxide of hydrogen, obviously admit of an explanation from the same cause. When a drop of deutoxide of hydrogen is let fall upon oxide of silver, oxygen gas is disengaged with such rapidity that a kind of explosion takes place. When this happens in a dark place there is a sensible disengagement of light; the teroxide of manganese, the peroxide of cobalt, the oxides of lead, platinum, palladium, gold, iridium, &c. likewise act with violence on this liquid, oxygen gas being disengaged with rapidity. In these cases, the deutoxide of hydrogen loses the half of its oxygen and is converted into water, while most of the oxides (though not all of them) are reduced to the metallic state. Here we see that the mutual repulsion between the oxygen in the two compounds, together with the loose state of combination of half the oxygen in the liquid and in several of the oxides, occasions its sudden disengagement. The light emitted is probably owing to the suddenness of the disengagement of the gas and the consequent compression of the air.

Why oxides expel oxygen from deutoxide of hydrogen.

The reason of the disengagement of oxygen from deutoxide of hydrogen, when several metals in powder are put into it, as silver, platinum, gold, osmium, iridium, rhodium, palladium, is probably owing to the attraction of these bodies for the oxygen. This attraction is sufficient to disengage the oxygen; but not to overcome its tendency to assume an elastic form. Hence, the oxygen, instead of uniting with these metals, flies off in the state of gas.

And metals also.

The electric theory enables us to explain with facility, why a binary compound is decomposed by the action of a third body. Chlorine decomposes the oxide of calcium, because when assisted by heat it becomes more negative than the oxygen; it therefore repels the oxygen and attracts the calcium, and these two forces acting together are sufficiently strong to expel the oxygen from the calcium, and to enable the chlorine to take its place. If we attempt to decompose the chloride of calcium by means of oxygen and heat, it is obvious that we must fail; because the chlorine cannot be displaced by a body less negative than itself. But as oxygen is more negative than chlo-

Why a binary body is decomposed by a third body.

rine when not exalted by heat, the decomposition probably might be effected at the common temperature of the atmosphere, were it not for the elasticity of the oxygen which prevents it from coming within the requisite distance.

Why sulphur decomposes metallic oxides. When sulphur is heated with a metallic oxide, it combines both with the metal and the oxygen. To the former it acts the part of a negative body; to the latter that of a positive. The way in which it may act in this double capacity has been already explained. And this double power in sulphur of uniting both with positive and negative bodies, when its energy is sufficiently exalted by heat, explains the reason why sulphur is capable of decomposing all metallic oxides without exception.

And chlorine. Chlorine is not capable of decomposing all oxides, though it can several. No doubt this depends upon the less degree of positive electricity in the bases of these bodies, compared to calcium. But if we mix these oxides with charcoal, and after heating the mixture, pass a current of chlorine over it, the oxides will be decomposed. Thus if we mix alumina and charcoal, silica and charcoal, boracic acid and charcoal, &c. put the mixture into a porcelain or glass tube, and after heating it to redness, pass a current of dry chlorine gas over it, we shall obtain chlorides of aluminum, silicon, and boron. The rationale of these decompositions is sufficiently obvious. Carbon, which is a strongly positive body, will exercise a powerful attraction for the oxygen of these oxides. This attraction, together with that of the chlorine, for the bases of the oxides, is sufficient to separate the oxygen and establish the chlorine in its place.

Power increased if the body can unite with both constituents. When a body is applied to a binary compound which is capable of combining with both its constituents, it seldom fails to produce a decomposition; though it would not have been able to have effected it, had it been capable of uniting only with one of the constituents. For example, when charcoal heated to redness is placed in contact with steam, it decomposes that fluid, though hydrogen being more strongly positive than carbon, ought not to be disengaged from oxygen by that substance. The reason of the disengagement is, that the charcoal combines both with the oxygen and the hydrogen of the water, to the one being positive, and to the other negative. It is for the same reason that oxygen is capable of decomposing most metallic sulphurets. It combines at once with both of the constituents, forming a metallic oxide and sulphurous acid.

This is the reason why chlorine decomposes all the iodides, while oxygen (though more powerfully negative) cannot.

Chlorine unites with both of the constituents of the iodide, which is not the case with oxygen.

Suppose that we have a neutral salt, as for example sulphate of potash, dissolved in water, and that we add to the solution a quantity of nitric acid, we have no means of determining what takes place, because no phenomena indicate whether a decomposition has been produced or no. The probability is, that when an acid is added to a neutral salt more powerfully negative than the acid which the salt contains, decomposition will take place. Because the new acid will be more powerfully attracted by the base, and will repel the old acid. But if the whole remains in solution in the water, we can have no evidence to prove that such a decomposition has taken place. There are indeed cases when the decomposition is indicated by a change of colour in the liquid. Thus nitrate of copper is *blue*, while muriate of copper is *green*. If into a blue solution of nitrate of copper we pour muriatic acid, the liquid immediately becomes green, indicating by this change of colour, that the muriatic acid has displaced the nitric.

When the acid of the salt happens to be gaseous or to be volatile and endowed with a strong smell, either of these circumstances will furnish indications of decomposition. Suppose we have a solution of acetate of potash in water, and that we pour into it a quantity of sulphuric acid, no precipitation would take place, but a strong smell of acetic acid would be disengaged from the acid, affording sufficient evidence that the acetic acid had been disengaged, and that the sulphuric acid had united with the potash in its place. Suppose the salt dissolved in water to be bicarbonate of soda, and that we pour into the solution sulphuric or nitric acid, the carbonic acid will immediately assume the gaseous state, a strong effervescence takes place, and the gas is disengaged.

When the acid added forms an insoluble salt with the base of the salt in solution, the insoluble salt will immediately fall to the bottom, and thus show to the eye that the salt has been decomposed. Thus if to a solution of nitrate of barytes, we add sulphuric acid, sulphate of barytes will precipitate, and free nitric acid will remain in the liquid.

Except when one or other of these indications present themselves, we have no evidence that the new acid has taken the place of the old. Hence Berthollet was of opinion that in many cases the new acid united to the salt, and formed a kind of double acid consisting of one base united to two acids. But

this opinion seems inconsistent with the whole series of chemical combinations. We very rarely find a third body capable of uniting with a binary compound, and the electrical theory of affinity shows us the reason why. But there is no doubt that an alteration in the temperature is capable of reversing the nature of the decomposition, and the reason of this is not difficult to find. If we add nitric acid to a hot solution of borax, and let the mixture cool, there will be deposited a quantity of crystals of boracic acid. Thus it appears that nitric acid is capable of separating boracic acid from soda, and uniting with that alkali in its place. Allow the boracic acid to remain, put the whole into a retort and apply heat, the boracic acid redissolves and again combines with the soda, while the nitric acid passes into the receiver. Here the fixity of the boracic acid, and the volatility of nitric acid at a high temperature, enable the boracic acid again to displace the nitric acid, and to form borax anew.

Double salts. When two neutral saline solutions are mixed together, we would naturally expect that the two salts should unite together and form a double salt. This frequently happens, and doubtless in a much greater number of cases than has hitherto been observed. The salts of potash and those of ammonia are particularly prone to form double salts; the same observation may be made of the salts of lead, copper and alumina.

Frequently when two salts are mixed they show no tendency to unite together. But if the mixed saline solution be evaporated, the two salts crystallize separately. This happens, for example, when we mix together solutions of saltpetre and sulphate of soda, or saltpetre and common salt. In such cases the two salts are both probably in a neutral state, or the electric energies of the acids and bases mutually destroy each other.

Double decompositions. In many cases when two salts are mixed they mutually decompose each other, and two new salts are produced. Thus when sulphate of ammonia and common salt are mixed, and heat applied, sal ammoniac sublimes, and sulphate of soda remains fixed. This decomposition is owing to the fixity of one salt and the volatility of the other. Heat is the agent that brings it about. If we mix together sal ammoniac and carbonate of lime and apply heat, carbonate of ammonia sublimes, and muriate of lime remains. The cause of this decomposition also, is the volatility of one of the salts, and the fixity of the other; and heat is equally the agent of the decomposition.

When solutions of nitrate of barytes and sulphate of soda

are mixed in the requisite proportions, sulphate of barytes pre-
cipitates, and nitrate of barytes remains in solution, and may be
obtained in crystals by evaporating the liquid.   In this case
the decomposition is produced by the insolubility of the sulphate
of barytes. . Similar decompositions are produced, and from the
same cause when we mix together solutions of nitrate of stron-
tian and carbonate of soda, nitrate of lime and oxalate of
ammonia, nitrate of lead and phosphate of soda, nitrate of silver
and common salt.   The cases of double decomposition have
been very well explained by Berthollet, and constitute the
most satisfactory and unobjectionable part of his *Chemical
Statics.*   They are all owing either to the volatility or the
insolubility of one of the salts formed.

Thus we have gone over the greater number of phenomena
attending chemical decompositions, without finding any which
appear incompatible with the electric theory.   There are, how-
ever, a few which we cannot at present explain in a satisfactory
manner, owing to the very imperfect investigation of the elec-
tric theory.   Of these I shall mention only one.   If the steam
of water be passed over red hot iron it is decomposed, hydrogen
gas is disengaged, and oxide of iron formed.   On the other
hand, if we heat oxide of iron surrounded with hydrogen gas,
water is formed, and the oxide reduced to the metallic state.
These two decompositions appear to be incompatible with each
other.   Hydrogen is undoubtedly much more *positive* than iron,
it ought therefore to be able to deprive this last metal of oxygen.
The reduction of the oxide of iron by means of hydrogen, is what
we should expect.   When iron decomposes steam, its tempera-
ture is raised to redness, and undoubtedly the temperature of
the steam is much lower.   Shall we conclude from this that
heat is capable of exalting the positive electricity of the iron,
so much as to enable it to surpass that of the hydrogen at a
lower temperature?   This at least is the only explanation
which occurs to me as at all approaching a satisfactory solution
of the difficulty.

Anomaly.

7. The tables which originated with Geoffroy, and which
Bergman improved so much, instead of being called tables of
affinity, should be considered as merely representing the order
of decomposition.   And if the order of decomposition were
regular and unvaried, such tables would be of considerable
utility.   Indeed they would constitute a very valuable acqui-
sition to the young practical chemist.   The order of decompo-
sition seems to be intimately connected with the electrical state

Tables of de-
compositions.

of the respective bodies. The reason why it varies seems to be, that the electrical state of a body is susceptible of variation according to the temperature, being exalted by heat and depressed by cold. This is the reason why the tables of the electric state of bodies are necessarily defective. I shall, however, venture to exhibit here a few tables of the non-metallic bodies, arranging them according to their electrical state. A number of the metals might have likewise been introduced; but there are so many of these bodies still very imperfectly examined, that the position of most of them would be little better than conjectural. The following table exhibits the non-metallic bodies in the order of their electricity, begining with the most positive, and ending with the most negative.

Hydrogen	Sulphur
Boron	Azote
Silicon	Iodine
Carbon	Bromine
Arsenic	Chlorine
Phosphorus	Fluorine?
Selenium	Oxygen.

Hydrogen is positive with respect to every body. Oxygen is negative with respect to every body. Sulphur is positive with regard to all the substances below it; but negative with respect to all the substances above it. The same thing applies to all the bodies in the table, each is negative to every body above it, and positive to every body below it.

The following tables exhibit the bodies with which each of these substances is capable of combining, arranged according to their greatest electro-negative energy, and therefore in the order in which they decompose each other.

1 Hydrogen.	2 Boron.	3 Silicon.	4 Carbon.	5 Arsenic.
Fluorine	Fluorine	Fluorine	Oxygen	Oxygen
Chlorine	Chlorine	Chlorine	Chlorine	Fluorine
Oxygen	Oxygen	Oxygen	Iodine	Chlorine
Bromine	Sulphur	Sulphur	Sulphur	Bromine
Iodine			Azote	Iodine
Sulphur				Selenium
Selenium				Sulphur
Carbon				Phosphorus
Phosphorus				
Arsenic				
Azote				

6 Phosphorus.	7 Selenium?	8 Sulphur.	9 Azote.	10 Iodine.	11 Bromine.
Oxygen	Oxygen	Oxygen	Chlorine	Oxygen	Chlorine
Fluorine	Chlorine	Chlorin e	Iodine	Chlorine	Oxygen
Chlorine	Bromine	Bromine	Oxygen	Bromine	
Bromine	Iodine	Iodine			
Iodine	Sulphur	Selenium			
Selenium					
Sulphur					

The only substance more electro-negative than chlorine, is oxygen. And as we know no substance more electro-negative than oxygen, of course no column under oxygen can be drawn up.

These columns are, several of them, necessarily imperfect, from the combinations of the substances standing at the head of them being still imperfectly known. But so far as they go, they mark the order of decomposition. Thus none of the substances in the first column is capable of separating fluorine from hydrogen; while all of them are capable of separating azote from hydrogen. The order of separation is the position in which they stand in the column: every substance being capable of separating all the bodies below it, from the substance standing at the head of the column; but none of the substances placed above it. Thus *bromine* is capable of separating iodine, selenium, sulphur, and phosphorus, from hydrogen; but not oxygen, fluorine, or chlorine.

E

PART I.

OF SIMPLE SUBSTANCES.

It has been already stated in the Introduction, that the simple substances at present known are 53 in number; of these there are five which seem capable of combining with all the others. They are the most electro-negative of all known bodies. Hence, when compounds containing them are decomposed by galvanism, they always attach themselves to the positive pole. When they combine with a certain portion of the other simple bodies, they form with them acids; when with the rest, they constitute bases or alkaline bodies, capable of uniting with and neutralizing the acids.

There are a few of the simple acidifiable bases, that bear a considerable resemblance to these five bodies. Thus, sulphur possesses the property of uniting with several simple bodies, and of forming with them acids. Thus, it forms an acid with hydrogen, arsenic, and antimony, and probably with several other bodies; it is capable also of uniting with several other simple bodies, and converting them into bases or alkalies. In this way it unites with lead, copper, silver, and various other bodies—and the sulphur acids and alkalies are capable of uniting with and neutralizing each other. Sulphur therefore might, without much impropriety, be arranged along with the first five simple bodies; but its resemblance to the acidifiable bases seems still closer. It seems better therefore to arrange it along with them; the same observations apply to selenium and tellurium, which are equally capable of forming acids and bases by uniting with certain other simple bodies.

There is a compound body called *cyanogen*, which bears so close a resemblance to the first five simple bodies, that unless we were precluded by the knowledge of its being a compound

body, it would be requisite to arrange them together. Should
the five first simple bodies ever be ascertained to be compounds,
(as they probably will be hereafter,) then cyanogen and these
bodies would be very properly placed together; at present we
are, under the necessity of separating them. To the first five
simple bodies I shall apply the epithet, *supporters of combustion*, the next seventeen I shall call *acidifiable bases*, and the
last 31, *alkalifiable bases*. These three divisions will occupy
our attention in the three following chapters.

CHAP. I.

OF THE SIMPLE SUPPORTERS OF COMBUSTION.

THE simple supporters of combustion at present known, are
the following five :

1 Oxygen,	4 Iodine,
2 Chlorine,	5 Fluorine.
3 Bromine,	

They act so important a part in chemistry, that the student
requires to be made acquainted with them as early as possible.
It is proper to mention, that *fluorine* has never yet been
obtained in a separate state, though the experiments of Davy
and the reasoning of Ampere have rendered its existence very
probable. We are, however, at present necessarily ignorant
of its properties. The other four supporters naturally divide
themselves into two groups; the first group contains only
oxygen, which differs materially from the other three. It does
not form an acid with hydrogen, and its electro-negative pro-
perties are greater than those of any other substance whatever.
Chlorine, bromine, and iodine, the substances which constitute
the other group, resemble each other very closely ; they form
acids with hydrogen ; they are positive with respect to oxygen,
combine with it and form acids bearing a very close resem-
blance to each other. They have the still more curious
property of combining with the alkalifiable bases, and forming
with them a set of compounds which possess all the charac-
ters of neutral salts.*   I shall treat of these five supporters in
their order in the five following sections.

* In consequence of this property, Berzelius has given them the name of
salt formers, corpora hologenia, saltbildare, salzbildar.

SECTION I.—OF OXYGEN.

Oxygen is a gaseous substance and constitutes one of the constituents of atmospherical air. It was discovered by Dr. Priestley on the 1st of August, 1774, and called by him *dephlogisticated air;* he procured it by exposing *red oxide of mercury* to the action of a powerful burning glass, while enclosed in a glass receiver standing inverted over mercury.* Scheele discovered it before 1775, without any previous knowledge of what Dr. Priestley had done ; he gave it the name of *empyreal air.*† Condorcet, who was secretary to the French Academy, gave it the name of *vital air.* Lavoisier first imposed the name oxygen, (from a plausible but erroneous hypothesis,) and this name very speedily came into general use. This term was made generally known to the public when the new Chemical Nomenclature was published in 1787; and within a very few years of that period it was generally adopted.

There are various modes of procuring oxygen gas. The simplest and cheapest is, to employ a bottle made of hammered iron by welding, about a quarter of an inch thick, rather flat, and capable of holding about an English pint. This bottle has a cylindrical mouth about an inch in diameter, into which is ground a piece of an old gun barrel open at both extremities and about a foot or 18 inches long. To the extremity of this piece of gun barrel, is fitted, by grinding, the extremity of the brass pipe *a.* This brass pipe is about 5 feet long,
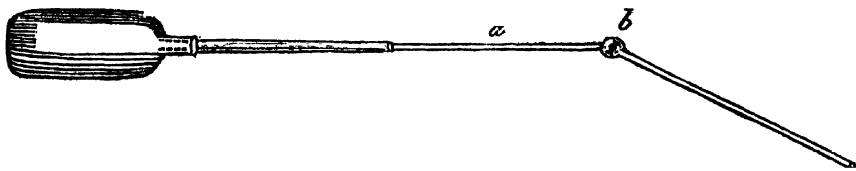
and it has a moveable joint *b,* which enables the mouth of it to be bent, so that it can be introduced into the open

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* Priestley on Air, vol. ii. p. 106.

† See Scheele on Air and Fire, passim. He procured the oxygen by distilling a mixture of sulphuric acid and saltpetre, and by heating the black oxide of manganese. Bergman in his Introduction to Scheele's book, dated 13th July, 1777, informs us that the work had been ready for publication about two years before. It is probable, from this, that Scheele's discovery of oxygen could not be much later than Priestley's.
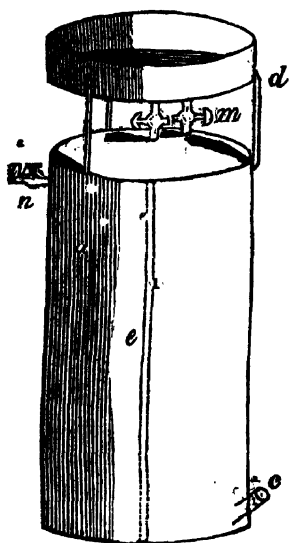
mouth *c* of the gas holder, previously filled with water. This gas-holder is a cylindrical vessel made of tinned copper, and may be of such a size as to hold 2000 cubic inches or more. Above it there is a vessel *d*, about four inches deep and of the same diameter with the gas-holder, with which it communicates by means of two tubes. The tube *e* in the centre passes down almost to the bottom of the gas-holder; but the tube *m* goes no farther than its top. Both of these tubes are furnished with stopcocks, by means of which the communication between the upper vessel and the gas-holder may be opened or shut at pleasure.
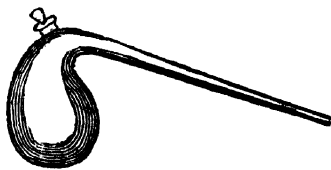
There is another tube *n*, furnished with a stopcock at the very top of the gas-holder. There is also a brass cover which may be screwed on the mouth *c*, and when it is on that mouth is effectually closed, so that the gas-holder may be filled with water by means of the tubes *e* and *m*, pouring the water into the upper open vessel and opening the stopcocks of the tubes *e* and *m*. When the vessel is filled with water, the stopcocks of the tubes *e*, *m*, and *n*, must be carefully shut; then the top may be taken off the tube *c*, because from the oblique insertion of the tube *c*, no air can get in, and consequently no water can run out.

The iron bottle is to be filled with good black oxide of manganese* previously ground to powder. The piece of gun barrel is to be introduced into the mouth of the bottle and made air-tight; the bottle is then to be introduced horizontally into a fire or wind furnace, capable of raising it and keeping it at a red heat. The flexible brass tube is then to be introduced into the end of the gun barrel and fixed air-tight; the other extremity of it is to be introduced as far as possible into the mouth *c* of the gas-holder, and then the joint *b* is to be screwed tight so as to keep the tube in one position and to prevent any air from escaping by the joint. As soon as the

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* A black mineral substance, to be afterwards described; it is found chiefly in Devonshire where it is raised by mining. The annual consumption of it in Great Britain amounts to about 30,000 tuns, nearly a third of which is consumed in Glasgow.

manganese begins to get red hot, it gives off oxygen gas in abundance, which passes along the tubes and rises to the top of the gas-holder, the water running out by the mouth *t* in proportion as the oxygen gas enters. If the manganese be pure, 11 ounces troy of it will give one ounce, or 1387 cubic inches of oxygen gas. But in general, in consequence of the impurity of the manganese, the produce is smaller.

Those persons who are not supplied with an iron bottle, may procure oxygen gas from the black oxide of manganese by the following process. Into the glass retort, (figured in the margin,) introduce a quantity of black oxide of manganese in powder, and pour over it as much concentrated sulphuric acid* as will make the whole into a magna of about the consistence of cream. Plunge the beak of the retort under the shelf of the water cistern, on which is placed an inverted jar filled with water. The beak of the retort must terminate under the mouth of this jar. Apply the heat of a lamp to the belly of the retort. Oxygen gas is immediately disengaged in great quantity. When black oxide of manganese is treated in this way it yields at least as much oxygen as by the former method, but the process is a great deal more tedious.

Red lead, and likewise red oxide of mercury, yield oxygen gas likewise when exposed to a red heat in an iron bottle; but in much smaller quantity.

Oxygen gas obtained from black oxide of manganese (chiefly on account of the impurity of the manganese) is never quite pure. But when pure oxygen gas is required, it may be obtained from the salt called *chlorate of potash.*† This salt is to be put into a very small bottle glass retort with rather a long beak. The belly of the retort is heated by a charcoal fire on a choffer to a dull red heat, while the beak is plunged under water; the salt decrepitates and gives out oxygen gas in abundance, which may be received either in jars or bottles furnished with ground stoppers. It is perfectly pure if care be taken to allow all the common air of the retort

How procured pure.

* For an account of this acid, see the next chapter in the section entitled, Of Sulphur.

† This is a white salt in shining rhomboidal plates, which will be described in a future part of this work.

to be expelled before beginning to collect it. 31 grains of chlorate of potash give out when thus treated 12 grains of oxygen. Hence, a troy ounce of the salt will furnish about 537 cubic inches of oxygen gas.

1. Oxygen gas is colourless and elastic, and possesses all the mechanical properties of common air. It has no perceptible taste, and is destitute of smell.

2. It is a little heavier than common air, but chemists are not yet agreed about its true weight. By a set of experiments, conducted with as much care as possible, I obtained 1·1117 for the specific gravity of oxygen gas; and Dr. Prout demonstrated long ago, that if air be a mixture of 80 volumes azotic and 20 volumes oxygen gas, then the true specific gravity of oxygen gas is 1·1111.* Hence, at the temperature of 60°, and when the barometer stands at 30 inches, 100 cubic inches of oxygen gas weighs 34·60 grains.

3. Combustible bodies burn with much more splendour, and give out more heat and light than when they burn in common air.

4. Animals are capable of breathing oxygen gas without any feeling of inconvenience, more than when they breath common air. An animal confined in a given volume of common air, unless that air be renewed, speedily becomes sensible

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* Annals of Philosophy, vi. 321. Chemists, in general, consider air as a mixture of 79 volumes azotic and 21 volumes oxygen gases. But I have given a set of experiments which appear to me, at least, decisive that the true composition is as Dr. Prout has stated. See First Principles of Chemistry, i. 95. Every other experimenter has made the sp. gravity of oxygen lower than 1·1111. Berzelius and Dulong made a careful set of experiments, and state the sp. gravities of oxygen and azotic gas as follows: (Ann. de Chim. et de Phys. xv. 386.)

$$\text{Oxygen gas,} \quad . \quad . \quad 1·1026$$
$$\text{Azotic gas,} \quad . \quad . \quad 0·976$$

But it is impossible that these two numbers can be exact. If air be a mixture of 21 volumes oxygen, and 79 volumes azotic gas, and if the above numbers be correct, then

$$\frac{21 \times x + 79 \times 0·976}{100} = 1$$

If we solve the equation, we get $x = 1·09028$; so that the sp. gravity of oxygen gas would be still less than Berzelius and Dulong found it. If their sp. gravities were correct, and air a mixture of 21 oxygen and 79 azote, then the sp. gravity of air would not be 1, but 1·002586. These facts are sufficient to show that the results of Berzelius and Dulong cannot possibly be accurate. As soon as chemists take the trouble to re-examine the subject, I have no doubt that they will ultimately find that the true sp. gravity of oxygen gas is 1·1111, as given in the text.

of a feeling of suffocation, and at last dies for want of fresh air. The same thing happens to an animal confined in oxygen gas; but the same volume of oxygen gas will serve an animal a much longer time for breathing than the same volume of common air; about four times as long.

5. Scheele and Lavoisier who first attempted to analyze atmospherical air, concluded from their experiments that it was a mixture of

Composition of common air.

27 volumes oxygen gas
73 volumes azotic gas

——
100

But the subsequent researches of Mr. Cavendish* demonstrated, that the proportions assigned by these chemists are inaccurate. And that air, supposing it dry, and free from all impurities, is a mixture of

Oxyen gas   .   .   20·833
Azotic gas   .   .   79·166
——————
100·

This determination remained for nearly 20 years unnoticed, and not adopted by chemists. It was confirmed by the experiments of Davy, about the beginning of the present century. Berthollet also confirmed it while in Egypt. These experimenters concluded, that atmospherical air is a mixture of 21 oxygen and 79 azotic gas; proportions which were confirmed by the subsequent experiments of Dalton and Gay-Lussac and Humboldt.

These proportions differ very little from the result of my own experiments. The mean of ten experiments in which I removed the oxygen from common air, by means of phosphorus, gave me air, a mixture of

Oxygen   .   .   20
Azotic gas   .   .   80
——
100

This result was confirmed by decomposing common air by means of hydrogen gas. The reason why experimenters in

* Phil. Trans. 1783, p. 107.

general obtain less than 80 per cent. of azotic gas, seems to be, that a small quantity of this gas is consumed during the experiment, probably it is converted into ammonia.

6. Oxygen is rather a bad refractor of light. If we reckon the refracting power of air unity, then that of oxygen gas, according to the result of the experiments of Dulong,* is 0·324.

7. When substances are burnt in oxygen gas, or in any other gas containing oxygen, if the air be examined after the combustion, we shall find that a great part of the oxygen has disappeared. If charcoal, for instance, be burnt in oxygen gas, there will be found, instead of part of the oxygen, another very different gas, known by the name of carbonic acid gas. The oxygen in this case combines with the combustible body. The new compound formed is called an *oxide*, or sometimes an *acid*. Exactly the same thing takes place when air is respired by animals; part of the oxygen gas disappears, and its place is occupied by substances possessed of very different properties.

8. Oxygen gas is not sensibly absorbed by water, though jarfuls of it be left in contact with that liquid. It has been ascertained, however, that water does in reality absorb a small portion of it, though not enough to occasion any perceptible diminution in the bulk of the gas. When water is freed from all air by boiling and the action of the air-pump, Dr. Henry ascertained, that 100 cubic inches of it will imbibe 3·55 inches of oxygen gas.† Saussure found that water in the same circumstances, absorbs 6·5 cubic inches of this gas.‡ But Mr. Dalton has rendered it probable that Saussure's estimate is considerably above the truth.§

9. The weight of an atom of oxygen in the subsequent part of this work will be denoted by 1. A volume of oxygen is equivalent to 2 atoms, provided we suppose, as I have done, that water is a compound of 1 atom of oxgen, and 1 atom of hydrogen.

SECTION II.—OF CHLORINE.

This substance was discovered by Mr. Scheele, and an account of it published by him in the Memoirs of the Swedish Academy of Sciences, for 1774, in his celebrated paper on Manganese, which had occupied him for three years.‖ He gave it the

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* Ann. de Chim. et de Phys. xxxi. 166.
† Phil. Trans. 1803, p. 174.   ‡ Annals of Philosophy, vi. 340.
§ Annals of Philosophy, vii. 218.
‖ Memoires de Chymie de M. C. W. Scheele, i. 67.

name of *dephlogisticated muriatic acid*, considering it as muriatic acid deprived of phlogiston. Berthollet made a set of experiments on it, about the year 1785, which were published in the Memoirs of the French Academy of Sciences. He considered himself to have proved that it is a compound of muriatic acid and oxygen; an opinion which was soon after adopted by the chemical world in general. On that account it received the name of *oxygenized muriatic acid*, which was afterwards contracted by Mr. Kirwan to *oxymuriatic acid*. The experiments of Scheele and Berthollet were repeated and varied by all the eminent chemists of the time. But the first great addition to the discoveries of these philosophers was made by Gay-Lussac and Thenard, and published by them in 1811, in the second volume of the *Recherches Physico-chimique*, p. 94. They showed that the opinion that oxymuriatic acid contains no oxygen might be supported. But at the same time assigned their reasons for considering the old opinion as well founded. An abstract of these important experiments had been published however in 1809.* These experiments drew the attention of Sir Humphry Davy to the subject, and he soon after communicated a paper to the Royal Society to show that no oxygen gas could be separated from oxymuriatic acid, nor any proof produced that it contained oxygen. This paper was published in the Philosophical Transactions for 1810.† It was speedily followed by another paper upon the same subject.‡ He drew as a conclusion that oxymuriatic acid is an undecompounded substance; on that account he applied to it the new name *chlorine*, from the green colour which it possesses.§ And this name has been generally adopted by chemists. Few chemists were disposed at first to accede to the opinion of Davy. But subsequent discoveries have greatly augmented the weight of his reasoning, and, at present, his view of the subject is, I believe, universally adopted.

It may be obtained by the following method. Put into a small glass retort a quantity of the black oxide of manganese in powder, and pour over it as much of the common muriatic acid of the shops as will make the whole into a very thin paste. Then plunge the beak of the retort into the water trough, and place over it a stout glass phial capable of holding about a

Preparation.

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* Memoires d'Arcueil, ii. 295.
‡ Phil. Trans. 1811, p. 1.
† P. 231.
§ From χλωρος, grass green.

quart, previously filled with water. Apply the heat of a lamp to the bottom of the retort. A gas is extricated which enters into the mouth of the inverted phial, displaces the water and fills it. As soon as the phial is full it is to be withdrawn and its mouth carefully stopped with a glass stopper, accurately ground so as to fit, and which must be previously provided. Other phials may be then substituted and filled in succession, till the requisite quantity of gas is obtained.

Manufacturers prepare it by mixing together common salt, black oxide of manganese, and sulphuric acid diluted with water. If the manganese be perfectly pure teroxide, the proportions of these substances to be employed are as follows:

Common salt . . .	7·5
Teroxide of manganese .	5·5
Sulphuric acid (sp. gr. 1·837)	12·25

The acid should be previously diluted with its own weight of water. The mixture is put into leaden stills enclosed in iron. The acid should be added in small quantities at a time. At first the chlorine comes off without any heat. After it ceases to be disengaged, the still should be heated by means of steam, and the contents of it should be frequently stirred to prevent the manganese from falling to the bottom, which would retard or stop altogether the extrication of the chlorine.

The extrication of the chlorine might be accomplished, though only half the sulphuric acid above stated were employed; but in that case the vessels would be much more injured. It is found on that account more economical to use a superabundance of sulphuric acid. Manufacturers know how to prevent this excess of acid from being lost.

Chlorine thus prepared, possesses the following properties.

Properties.   1. It has a yellowish green colour. The consequence of which is, that a phial filled with it has the appearance of being filled with a transparent yellowish green vapour. Its smell is strong and suffocating, similar to that of *aqua regia*. When a person is obliged to inspire the fumes of chlorine, it produces a most insufferable sensation of suffocation, occasions a violent cough with much expectoration, which continues for some time, and brings on a very great degree of debility. Its taste is astringent. Thus it is distinguished from oxygen gas by its colour, taste, and smell.

Sp. gravity.   2. Its specific gravity was at first stated too low, obviously because the specimen examined had not been quite free from

all admixture of common air. Davy stated it to be 2·392.* But in his Elements of Chemical Philosophy, published in 1812, he says, that 100 cubic inches of it weigh between 76 and 77 grains.† If we take the mean of these two numbers, the specific gravity will be 2·4568. Gay-Lussac and Thenard determined the specific gravity of this gas to be 2·4700.‡ They ascertained the purity of the gas employed by causing it to be absorbed by caustic potash, after having proved that it contained no carbonic acid. Nothing is said in these experiments about drying the gas. If it contained vapour of water, it is obvious that the numbers given would be below the truth. A careful set of experiments, made in my laboratory, gave the specific gravity 2·5. This was the specific gravity already deduced by Dr. Prout, from theoretical considerations. I have no doubt that it is the true gravity of chlorine gas.

3. It refracts light very powerfully. According to Dulong, if we reckon the refracting power of air 1, that of chlorine will be 2·628.§

4. When any vegetable blue colour is exposed to the action of chlorine, it is immediately destroyed, and cannot afterwards be restored by any method whatever. Indeed chlorine possesses the property of destroying all vegetable colours, and of rendering coloured bodies white. This property was first observed by Scheele. The knowledge of it induced Berthollet to propose the introduction of chlorine into the practice of bleaching. This suggestion has been successfully adopted in Great Britain and Ireland. At present all the great bleaching works, in this country, employ chlorine as the grand whitening agent. For the first introduction of it we are indebted to Mr. Watt.‖

Destroys colour.

The process followed is to combine unslacked quicklime and chlorine, by leaving them for a sufficient time in contact. The compound thus formed is usually called *bleaching powder*. It is a *chloride of lime*. At first it consisted of two atoms of lime united to one atom of chlorine. But now it is manufactured in Glasgow so strong, as to be a compound of one atom of

Bleaching powder.

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* He states in his researches on oxy-muriatic acid, (Phil. Trans. 1810), that 100 cubic inches of it, under the mean pressure and temperature weigh 74·5 grains.

† P. 236.

‡ Recherches Physico-Chimique, ii. 125.

§ Ann. de Chim. et de Phys. xxxi. 166.

‖ See Annals of Philosophy, viii. 1.

chlorine and one of lime.   This powder is dissolved in water.
The cloth is first boiled in an alkaline ley, and the temperature
is raised somewhat higher than that of boiling water.   It is
then, after being washed, steeped in the solution of chloride
of lime.   If the bleaching be not completed by this first pro-
cess, it is again repeated.   Cotton is much more easily bleached
than linen, by this process.

5. If a lighted taper be plunged into a phial filled with
chlorine gas, it continues to burn with a low red flame, emit-
ting much smoke, but giving out but little light.   If a piece
of phosphorus be put into this gas it takes fire of its own accord,
burning with a pale yellowish green light.   Antimony, like-
wise, arsenic, zinc, iron, and several other metals, take fire of
their own accord when plunged into chlorine, and burn with
considerable splendour.   During all these cases of combustion
the quantity of chlorine diminishes, and if the portion of com-
bustible be sufficient, the gas disappears altogether.   The
combustible is totally altered in its appearance and converted
into a new substance, which has received the name of *chloride*.
This chloride is a compound of the combustible substance and
the chlorine.

6. If an animal be plunged in an atmosphere of chlorine, so
as to be obliged to breathe it in a pure state, it dies almost
instantly.   This gas then is incapable of supporting animal
life.   In this respect it differs entirely from oxygen gas.

Liquified by water.
7. When this gas is exposed to a pressure of about four
atmospheres, and at the same time cooled, it is condensed into
a liquid, as was first discovered by Mr. Faraday.*   Liquid
chlorine is a limpid yellow coloured fluid, exceedingly volatile.
When the pressure is removed it is very rapidly dissipated, and
with considerable violence.   When cooled down to 0°, before
taking off the pressure, it produces so much cold by evaporating,
that a portion remains fluid, even at the common pressure of
the air.   The temperature in this case must be below —40°.
For Davy showed that chlorine gas does not liquefy at
—40°.   The specific gravity of liquid chlorine is very nearly
1·33.   Its refracting power is a little less than that of water.
It is a non-conductor of electricity.

8. Water absorbs this gas with considerable rapidity, pro-
vided the gas be pure; but much more slowly when it is mixed
with air or any other foreign gas.   According to the experi-

* Phil. Trans. 1823, p. 160.

ments of Dalton, one volume of water at the ordinary temperature, and under the common pressure, absorbs two volumes of chlorine gas.* . The water acquires the greenish yellow colour, the disagreeable smell, the astringent taste, and the whitening qualities of the gas itself.

When this liquid is kept for some time in a temperature as low as 36°, crystals in plates of a strong yellow colour appear in it. These crystals are more readily obtained, if a little water be put into a phial filled with chlorine gas, and the whole left for some time at a temperature of 33° or 34°. These crystals had been observed soon after the discovery of chlorine gas. But it was Davy who first ascertained them to be a compound of chlorine and water. The crystallization goes on best in a dark place. The crystals are sometimes long needles; sometimes they appear octahedrons, or, at least, exhibit octahedral faces. . When the phial is exposed to the light, the crystals attach themselves to the side next the window, as is the case with camphor. The specific gravity of these crystals at 32°, as determined by Mr. Faraday, is 1·2. These crystals act upon different substances, nearly as chlorine gas would do. When they are thrown into alcohol, the temperature rises 8 or 10 degrees, a pretty violent action takes place, chloric ether and muriatic acid are formed, and likewise a small quantity of a triple compound of chlorine, carbon, and hydrogen. This hydrated chlorine was analyzed by Mr. Faraday, who found it a compound of

Chlorine	. .	27·7
Water	.	72·3

100†

Now it will appear afterwards that the atom of chlorine weighs 4·5, and the atom of water 1·125. If we consider the chlorine in the compound, as constituting 1 atom, then the water is a little more than ten atoms: for $27·7 : : 72·3 : : 4·5 : 11·746$. Now ten atoms of water weigh 11·25. The 0·496 of excess is not so much as half an atom. And doubtless it existed mechanically lodged between the plates of the crystals. These crystals then constitute a *deci-hydrate* of chlorine‡ composed of

* Dalton's New System of Chemistry, ii. 293.
† Royal Institution Journal, xv. 71.
‡ I express the number of atoms of the substance which acts the part of an acid in a compound by prefixing the Latin numerals; and the number of atoms of the base, by prefixing the Greek numerals.

$$1 \text{ atom chlorine} = 4\cdot5$$
$$10 \text{ atoms water} = 11\cdot25$$

$$15\cdot75$$

9. When chlorine in combination with any other body is exposed to the action of the galvanic battery, the compound is decomposed and the chlorine is deposited at the positive pole, while the other substance is deposited at the negative pole. The only exception to this rule is when chlorine and oxygen are in combination; in such a case the oxygen is given off at the positive pole, and the chlorine at the negative pole. At high temperatures chlorine displaces oxygen from its combination with several of the metals and unites with them itself.

10. Chlorine gas may be exposed to a very high temperature by passing it through a white hot porcelain tube, without experiencing any change.

11. Chlorine has the property of combining with oxygen, and of forming four distinct substances, which have been particularly examined. We cannot form the combination directly. All these compounds are obtained by means of a salt first prepared and described by Berthollet. It was long distinguished by the name of *hyperoxymuriate of potash*, a name which has been changed into *chlorate of potash*. It is obtained by dissolving a quantity of the common potash of the shops in water, and causing a current of chlorine gas to pass through the solution as long as it continues to be absorbed. After some time flat rhomboidal crystals possessing considerable lustre are deposited; these crystals constitute the salt in question. Let us explain the way in which the different compounds of oxygen and chlorine may be obtained from it.

(1.) When this salt is put into a small glass flask and muriatic acid poured over it, an effervescence takes place and a greenish yellow gas is extricated in abundance. If the muriatic acid be diluted with water, and the quantity of salt with which it is mixed be considerable in proportion to that of the acid, and if a very gentle heat only be employed, a gas is extricated very slowly, which may be received in small glass jars standing over mercury. After the gas has been prepared in this manner, it is better to allow it to remain for 24 hours in contact with the mercury. For, as originally prepared, it always contains a good deal of chlorine gas mixed with it, which disguises and greatly injures its properties. Mercury

has the property of absorbing and uniting with chlorine, while it does not act upon the new gas. It therefore gradually removes the chlorine, and leaves the new gas in a state of purity.

The new gas prepared in the way just described was discovered, in 1811, by Sir Humphry Davy, who gave it the name of *euchlorine.** But it will be better to distinguish it by the appellation of *protoxide of chlorine*, indicating, by that name, that it is a compound of chlorine with the smallest quantity of oxygen with which it is capable of combining. It possesses the following properties.

Its colour is much more intense and more yellow than that of chlorine. When contained in a small glass tube it still appears of a very lively yellow, whereas chlorine, in the same circumstances, would scarcely be visible.

Its smell resembles that of burnt sugar, mixed, however, with the odour of chlorine. In all probability this last odour is owing to the presence of a small portion of this gas. For it is extremely difficult to free it completely from chlorine.

When a moderate heat is applied to a vessel filled with protoxide of chlorine, an explosion takes place, and the gas is decomposed into a mixture of chlorine and oxygen gas. A very gentle heat is sufficient to produce this decomposition, sometimes even the heat of the hand will do it. The explosion is but feeble. According to the experiments of Davy, five volumes of protoxide of chlorine become six when decomposed, and the decomposed gas is a mixture of two volumes of chlorine, and one volume of oxygen.† Hence it is composed by weight of

Chlorine . . 5·000	81·82	4·50
Oxygen . . 1·111	18·18	1·00
	100·00	

Now if we make 1·00 represent the weight of an atom of oxygen, the atoms of chlorine will be 4·5. So that protoxide of chlorine is a compound of one atom of chlorine and one atom of oxygen.

From the preceding data it follows that the specific gravity of protoxide of chlorine is 2·444, supposing the specific gravity of air to be 1.‡

This gas destroys vegetable colours, as well as chlorine; but it first gives blue colours a tint of red.

* Phil. Trans. 1811, p. 155.   † Ibid. p. 157.

‡ Mr. Harvey at my request tried the specific gravity of this gas in my laboratory. He obtained 2·400, which I consider as a good approximation.

I.   F

Several substances, as phosphorus, take fire when they come in contact with protoxide of chlorine, and occasion an explosion.

Water absorbs eight times its volume of this gas and acquires an orange colour, and the peculiar smell of the gas.

2. Quadroxide of chlorine. (2.) The quadroxide of chlorine was discovered about the same time by Sir Humphry Davy and Count Von Stadion, of Vienna; but Davy's account of it was published sooner than that of Count Von Stadion.* The method of obtaining it is as follows: mix together a small quantity (not more than 50 grains) of chlorate of potash in powder with sulphuric acid, till the whole forms a dry paste, which will have an orange colour. Put this paste into a small glass retort, and plunge the belly of the retort into hot water, and keep it in that position for some time, taking care that the temperature of the water never becomes so high as 212°. A bright yellowish green gas separates from the paste, which must be received in small glass jars standing over mercury. This gas constitutes the deutoxide of chlorine. It possesses the following properties.

Properties. Its colour is a still brighter yellowish green than that of protoxide of chlorine. Its smell is peculiar and aromatic, without any mixture of the smell of chlorine. Water absorbs, at least, seven times its volume of this gas. The solution is deep yellow, and has an astringent and corrosive taste, leaving a disagreeable and lasting impression on the tongue. It destroys moist vegetable blues without previously reddening them. It does not act upon mercury, nor upon any of the combustible substances, tried by Davy, except phosphorus; which, when introduced into the gas, occasions an explosion, and burns with great brilliancy.

When heated to the temperature of 212° it explodes with more violence than protoxide of chlorine, giving out much light. Two volumes of quadroxide of chlorine when thus exploded are converted into three volumes, consisting of a mixture of two volumes of oxygen and one volume of chlorine.† Hence it is composed by weight of

Composition.

Chlorine .	.	2·5	4·50
Oxygen .	.	2·222	4·00

Now as the weight of an atom of chlorine was represented by

* Davy's account is published in the Philosophical Transactions for 1815, p. 214, Count Von Stadion's in Gilbert's Annalen der Physick, lii. 179, published in February, 1816.

† Davy, Phil. Trans. 1815, p. 216, and Gay-Lussac, Ann. de Chim. et Phys. i. 220.

4·5, and that of an atom of oxygen by one, we see from the last column of the preceding table that the deutoxide of chlorine is composed of one atom of chlorine combined with four atoms of oxygen.*

From the preceding data it is obvious that the specific gravity of quadroxide of chlorine must be 2·361, supposing that of common air to be 1·000.

(3.) The third compound of chlorine and oxygen is called *chloric* acid. It was first obtained in a separate state by M. Gay-Lussac. It is the acid which exists in chlorate of potash. His method of obtaining it in a separate state was as follows: he prepared chlorate of barytes by the method pointed out by Mr. Chenevix, which will be described in a subsequent part of this work. This salt was dissolved in water, and dilute sulphuric acid cautiously added to it as long as any precipitate continued to fall. By this method all the barytes was removed from the liquid without adding any excess of sulphuric acid, so that on filtering nothing remained but *chloric acid* held in solution by the water. This acid possesses the following properties.† 3. Chloric acid.

It has no sensible smell. Its solution in water is colourless, and it reddens vegetable blues without destroying them. Light does not decompose it. It may be concentrated by a gentle heat without undergoing decomposition, and without being volatilized along with the water. When concentrated it has somewhat of an oily consistency. When heated it is partly decomposed into chlorine and oxygen, and partly volatilized without alteration. Muriatic acid decomposes it in the same manner without the necessity of applying heat. It combines with the different bases and forms the genus of salts called *chlorates*, to be described in a subsequent part of this work. Properties.

When 100 parts of dry chlorate of potash are exposed to a red heat in a retort, a quantity of oxygen gas is driven off, which weighs 38·88 parts.‡ The residue weighing 61·12

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* According to Count Von Stadion, its constituents are two volumes chlorine and three volumes oxygen. This would make it a compound of one atom chlorine and three atoms oxygen. But the properties of the substance described by the Count differ so much from those of the gas examined by Davy, that it is probable they are distinct substances. The reader will find an account of the properties of the deutoxide of chlorine of Count Von Stradion in the Annals of Philosophy, vol. ix. p. 22.

† Gay-Lussac, Annals of Philosophy, vi. 129.

‡ Berzelius in a late experiment obtained 39·15 gr. of oxygen, which almost coincides with the number in the text.

parts, is a compound of 32·196 of potassium and 28·924 of chlorine.* But 32·196 of potassium require, in order to be converted into potash (in which state they existed in the salt), 6·576 of the oxygen. There remain 3?·304 of oxygen, which must have been combined with 28·924 of chlorine, and this compound must have constituted chloric acid. According to this statement chloric acid is composed of

Composition.

Chlorine	.	.	28·924	4·50
Oxygen	.	?	32·304	5·02

We see from the last column that it is a compound of one atom of chlorine and five atoms of oxygen. For the weight of an atom of chlorine is 4·5, and that of an atom of oxygen one.†

4. Perchloric acid.

(4.) The fourth compound of chlorine and oxygen is likewise an acid. We may distinguish it by the name of perchloric acid. It was discovered by Count Von Stadion, and may be obtained in the following manner.

, When the quadroxide of chlorine is extricated from a mixture of sulphuric acid and chlorate of potash, a peculiar salt is formed which remains behind in the retort. We obtain this salt best when we use three or four grains of strong sulphuric acid for every grain of chlorate of potash employed. After the first violent action of the acid is at an end, heat is to be applied and continued till the yellow colour of the mass disappear. The salt formed in this way is mixed with bisulphate of potash,‡ which may be separated by a second crystallization. The purified salt possesses the following properties.

Properties.

It is quite neutral,|| it is not altered by exposure to the air, and has a weak taste similar to that of muriate of potash.§ It dissolves in considerable quantity in boiling water; but water of the temperature 60°, dissolves only $\frac{1}{33}$th of its weight of it. In alcohol it is quite insoluble. Its crystals are

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* That this is the case will be shown in a subsequent part of this work. The evidence would not be understood here, if it were given.

† Sir H. Davy considers chloric acid as a compound of one atom chlorine and six atoms oxygen. The reason is, that he believes the potash to exist in the sak in the state of potassium, and therefore adds the other atom of oxygen, which we have supposed in the text to be united to the potassium, to the chlorine.

‡ A salt which will be described in a subsequent part of this work.

|| That is to say, it does not affect the colour of vegetable blues.

§ Or *chloride of potassium*, a substance to be described in a subsequent part of this work.

elongated octahedrons similar to the primitive form of sulphate of
lead, and resembling the variety which has two prismatic faces
between the pyramids.* It detonates feebly when triturated in
a mortar with sulphur.• When heated to the temperature of
412° it is decomposed and converted into *chloride of potassium*†,
and oxygen gas. When it is mixed with its own weight of
sulphuric acid and exposed to a heat of 280° in a retort, it is
decomposed, and the acid which it contains may be distilled
over. The acid may likewise be formed artificially by expos-
ing quadroxide of chlorine to voltaic electricity in an apparatus
constructed with platinum wires. According to the experi-
ments of Count Von Stadion, when this salt is exposed to heat
it yields 45·92 parts of oxygen gas, and there remain 54.08
parts of chloride of potassium. Now 54·08 of chloride of pot-
assium are composed of

Potassium	. .	28·49
Chlorine	. .	25·59
		————
		54·08

But 28·49 parts of potassium require 5·819 parts of oxygen in
order to be converted into potash. There remain 40·1 parts
of oxygen. According to this result perchloric acid is com-
posed of

Chlorine	. .	25·59	4·500
Oxygen	. .	40·1	7·012

Hence it appears that this acid is a compound of one atom of
chlorine and seven atoms of oxygen.‡ The experiments of
Count Von Stadion have been confirmed by those of Davy.

Thus it appears that the four compounds of chlorine and
oxygen are composed as follows.

	Chlorine.		Oxygen.
1. Protoxide of chlorine	1 atom	+	1 atom
2. Quadroxide of chlorine	1	+	4
3. Chloric acid .	1	+	5
4. Perchloric acid .	1	+	7

But if we were to take Count Von Stadion's analysis of quad-
roxide of chlorine as exact, it would be a compound of one
atom chlorine with three atoms oxygen; and in that case all

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* This variety is called *plomb sulphaté semiprismé* by Haüy, and is figured
by him in his 69th plate, figure 73.

† A combination of chlorine and potassium.

‡ Gilbert's Annalen der Physick. lii. 213.

the compounds would consist of an atom of chlorine united
with an odd number of atoms of oxygen. *

12. A volume of chlorine may be considered as equivalent
to an atom, while a volume of oxygen gas is equivalent to
two atoms. Hence, if a body be a compound of two volumes
chlorine and one volume oxygen, we know that it consists of
one atom chlorine and one atom oxygen.

SECTION III.—OF BROMINE.

Discovery.   This substance was discovered by M. Balard of Montpelier,
who investigated its properties and made it known to the public
by a memoir, which was read to the Royal Academy of Sciences
of Paris, on the 3d of July, 1826. This memoir was so com-
plete and so accurate, that little was left for the future investi-
gation of chemists. A few additional facts have been since
added by Liebig, Serullas, and Berzelius.

It was obtained by him from the mother water of the brine
springs in the neighbourhood of Montpelier; and there are
strong reasons for believing it to be a constituent of brine
springs in general, and to exist also in sea water. Liebig
found it in some of the salt springs in Germany,* and Mr.
Graham extracted it from the *spirit of salt*† of the Saltcoats
salt works, obtained by evaporating the sea water in the Frith
of Clyde.

In this mother ley bromine seems to exist in the state of
bromide of magnesium. Balard's process for extracting it is as
follows.

Preparation.   A current of chlorine gas is passed through the liquid, till it
acquires a brown colour. Care must be taken not to add too
much chlorine, otherwise the product of bromine will be dimin-
ished. The chlorine displaces the bromine, sets it at liberty,
and unites with the magnesium in its place. A quantity of
sulphuric ether is now poured on the liquid in a phial, taking
care that the phial is completely filled with liquid. The two
liquids being well mixed by agitation, are left for a little in a
state of rest. The ether soon swims on the top. It has dis-
solved the whole of the bromine, and acquired a beautiful
hyacinth red colour. The mother water, by this agitation, has
lost the peculiar smell of bromine, which distinguished it before,

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* Ann. de Chim. et de Phys. xxxiii. 331.
    † *Spirit of salt* is the name given in Scotland to a liquid that drops from
salt formed by evaporating sea water to dryness. It is chiefly a strong
solution of sulphate of magnesia and chloride of magnesium.

and acquired the smell of ether. The ether is now agitated with a strong solution of caustic potash. It loses its peculiar colour and smell, and the potash, being agitated with successive portions of ether thus impregnated with bromine, gradually loses its alkaline properties, and is changed into a saline matter which crystallizes in cubes.* These cubes are reduced to powder, mixed with purified teroxide of manganese, and put into a small retort, the beak of which plunges into a quantity of water with which the receiver is nearly filled. A quantity of sulphuric acid, diluted with its own weight of water, is poured upon the mixture of bromide of potassium and black oxide of manganese, and heat is applied. Red vapours rise, which condense in drops on the beak of the retort, and fall to the bottom of the receiver. The bromine which passes over in the state of vapour dissolves in the water; but the drops remain at the bottom, and gradually collect into a dark red liquid. At the end of the process the water is removed, and the bromine is obtained free from water, by distilling it off chloride of calcium.†

1. Bromine‡ thus obtained is liquid of a brownish red colour, so intense that it appears opaque; but when made to trickle down the sides of the glass, it appears transparent, and has a hyacinth red colour.

2. Its smell is very disagreeable, and has some resemblance to that of protoxide of chlorine; but is stronger and more suffocating.

3. Its taste is sharp and strong, and when taken internally, even in small quantities, it acts as a violent poison. A single drop of it put into the bill of a bird caused instant death.

4. It acts with energy upon organic bodies, wood, cork, &c., and particularly upon the human epidermis, which it corrodes, giving it a yellow tinge. This colour disappears after a few hours; but if the bromine be allowed to remain in contact for a certain time, the colour does not disappear till the epidermis be renewed.

5. Its specific gravity is 2·96.

6. It remains liquid at zero; but according to M. Serullas,

* These cubes are *bromide of potassium.*
† Balard, Ann. de Chim. et de Phys. xxxii. 342.
‡ M. Balard called it at first *murine,* but he was induced to give it the name of *bromine* (from ϐρωμος, *fœtidus*) at the suggestion of MM. Vauquelin, Thenard, and Gay-Lussac. See Ann. de Chim. et de Phys. xxxii. 382, and ibid. xxxiii. 223.

when cooled down to —4°, it becomes solid all at once, and becomes quite brittle.

7. It is exceedingly volatile—a single drop put into any vessel, immediately fills it with a vapour, exactly similar to the vapour given out by fuming nitric acid. It boils when heated to the temperature of $116°\frac{1}{2}$. No experiments have been made to determine the specific gravity of its vapour; but from the low temperature at which it boils, this specific gravity is undoubtedly high.* The vapour of bromine may be passed through a red hot tube without experiencing any alteration.

8. It is a non-conductor of electricity. A voltaic battery which was decomposing water very well, when the wires from the two poles were plunged into the liquid ceased to act, when a column of bromine, about three lines thick, was interposed. Nor is bromine decomposed, or in the least altered by the action of voltaic electricity. But the experiments of M. de la Rive have shown, that water holding bromine in solution, is an excellent conductor of electricity.†

9. When a burning taper is plunged into the vapour of bromine it is extinguished; but it burns for some instants with a flame green at the base and red at the upper part, as happens when it is plunged into chlorine gas. But when the metals come in contact with this vapour, a brilliant combustion is the consequence. This, at least, is the case with iron. Arsenic, also, and antimony, burn brilliantly when they come in contact with bromine.‡ When phosphorus is dropt into bromine, a violent detonation takes place. Thus, it appears, that bromine supports combustion almost as well as chlorine.

10. Bromine destroys vegetable colours almost as powerfully as chlorine itself. Even the solution of indigo in sulphuric acid is immediately discoloured by it.

11. Bromine dissolves, though only in small quantity, in water. The solution has a yellow colour. It is more soluble in alcohol, and much more so in sulphuric ether. Olive oil acts on it slowly. It is scarcely soluble in sulphuric acid.

12. When bromine is dropt into a solution of starch, it gives it a fine orange colour. Starch then may be employed as a pretty delicate reagent to detect the presence of bromine.

* I have shown (*First Principles*, i. 244) that the specific gravity of iodine vapour is obtained by multiplying its atomic weight by 0·555. The same should hold with vapour of bromide. If so, its specific gravity will be 5·5555.

† Ann. de Chim. et de Phys. xxxv. 160.

‡ Serullas, Ann. de Chim. et de Phys. xxxviii. 318.

13. The atomic weight of bromine can only be determined by analyzing the compounds into which it enters. We have three series of experiments made on purpose to determine this point.

(1.) Balard decomposed *bromide of potassium** by means of sulphuric acid, and he concluded from his analysis that an atom of bromine weighs 9·326.†

(2.) Liebig decomposed 2·521 parts of bromide of potassium by means of nitrate of silver. He obtained 4·041 parts of bromide of silver. From this he concludes, that the atom of bromine weighs 9·411.‡

(3.) Berzelius prepared a quantity of very pure bromide of silver, which he decomposed by chlorine gas assisted by heat. He found that 7·202 parts of bromide of silver, yielded 5·546 parts of chloride of silver; and that 7·880½ parts of bromide of silver yielded 6·069 parts of chloride of silver.§ The mean of these two experiments gives us 9·942 for the atomic weight of bromine. We may, therefore, adopt 10 for the atomic weight without any sensible error.

Such are the properties of bromine as far as they have been investigated. But it combines both with oxygen and with chlorine, and forms compounds which we shall now describe.

1. As far as is known at present, bromine and oxygen unite only in one proportion, and form a compound which possesses acid properties, and on that account has received the name of *bromic acid.*

When bromine is agitated with a sufficiently concentrated solution of potash, two different compounds are formed; namely, hydro-bromate of potash, which remains in solution; and bromate of potash, which, being very little soluble in water, precipitates in a white crystalline powder. This salt has many properties similar to those of chlorate of potash or of saltpetre. Its properties will be described in a subsequent part of this work.

When bromine and chlorine are placed in contact, they combine into a liquid, which has been called *chloride of bromine.* It is a liquid, which undergoes decomposition, if it be agitated

* This salt will be described in a subsequent part of this work.
† Ann. de Chim. et de Phys. xxxii. 356. I do not clearly understand the data on which the analysis is founded.
‡ Ibid. xxxiii. 352. Liebig has not given us sufficient data to enable us to judge of the accuracy of his analysis.
§ Poggensdorf's Annalen der Physick. xvi. 566.

with a concentrated solution of barytes. Two salts are formed; namely, the hydrobromate of barytes, which remains in solution; and the bromate of barytes, which being but little soluble, falls to the bottom. The bromate of barytes may be obtained under the form of acicular crystals, soluble in boiling water, and fusing with a green flame when placed upon burning coals. If dilute sulphuric acid be dropt into an aqueous solution of bromate of barytes, in the requisite quantity, the barytes is thrown down, and there remains a solution of bromic acid in water.

By a gentle evaporation the greatest part of the water may be driven off. There then remains a syrupy liquid, which cannot be deprived of the whole of its water. When the attempt is made, the acid undergoes decomposition, and is converted into bromine and oxygen. This decomposition takes place equally, if we leave it in the exhausted receiver of an air-pump standing over concentrated sulphuric acid.

Properties.

Bromic acid reddens litmus paper, and then discolours it. It has scarcely any smell. Its taste is very acid, but not caustic.

Nitric acid and sulphuric acid have no action on it. The latter, indeed, when concentrated, occasions an effervescence; oxygen gas being disengaged and bromine set at liberty. But this is probably owing to the high temperature produced by the action of the sulphuric acid on the water of the bromic acid. For it does not take place when the sulphuric acid used has been diluted with water.

It is decomposed by the hydracids, and by sulphurous acid, whether they be in an isolated state, or combined with a base.

Composition.

When dropt into nitrate of silver it occasions a white precipitate, which seems to be bromate of silver. It likewise precipitates concentrated solutions of lead; but the precipitate is redissolved when a little water is added. It also throws down a white precipitate, when added to the proto-nitrate of mercury.

When bromate of potash is heated, it gives out oxygen gas, and is converted into bromide of potassium. M. Balard, by this process, converted 1·128 parts of bromate of potash into 0·79 parts of bromide of potassium. The oxygen gas given out, therefore, amounted to 0·338 parts.* Now if the atom of

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* Bromide of potassium is a compound of

Bromine	. .	10
Potassium	. .	5
		15

or two-thirds of its weight are bromine.

bromine be 10, it is obvious that 0·79 of bromide of potassium
must be composed of

Bromine . . ·5266
Potassium . ·2633

Consequently bromic acid must be a compound of

Bromine . . 0·5266 or 10
Oxygen . . 0·2853 or 5.41

For 0·0526 of the oxygen were united to the potassium, and
converted it into potash.

Thus we see that one atom of bromine is united in this acid
with rather more than 5 atoms of oxygen. It is probable from
analogy, that 5 atoms of oxygen is the exact quantity. The
slight excess may have been owing to errors in the experiment;
perhaps the salt might have contained traces of water. For
nothing is said by Balard about the mode which he took to
dry it.*

2. We are acquainted at present with only one compound Chloride of bromine.
of chlorine and bromine. It is a very volatile liquid, the proper-
ties of which have hitherto been examined only by M. Balard.
To form it, we have only to pass a current of chlorine over
bromine, and to condense the vapours formed, by passing them
into a receiver, surrounded with a mixture of snow and salt.

Chloride of bromine is a liquid of a reddish yellow colour;
much lighter than the colour of bromine. Its smell is strong
and disagreeable, and it occasions a sudden flow of tears. Its
taste is excessively disagreeable.

It is very fluid and very volatile. Its vapour has a colour Properties.
somewhat like that of protoxide of chlorine.

Metals plunged into it, or brought in contact with it, become
incandescent, and no doubt chlorides and bromides of these
bodies are formed.

It dissolves in water. The aqueous solution acquires the
colour and odour of the chloride of bromine, and like it has
the property of rapidly discolouring litmus paper, and of de-
stroying vegetable colours in general.

When potash or soda is added to this aqueous solution, the
chloride undergoes decomposition, and alkaline muriates and
bromates are formed. These decompositions show that chlo-
rine is more powerfully negative than bromine.

No experiments have been yet made to determine the com-
positions of chloride of bromine. Were we to reason from

* Balard; Ann. de Chim. et de Phys. xxxii. 365.

analogy, we would conclude that it is a compound of 2 atoms chlorine, and 1 atom bromine, which would make its atomic weight 19. It does not seem to possess the characters of an acid, and cannot be combined with bases, without undergoing decomposition.

SECTION IV.—OF IODINE.

History.   This substance was discovered in the year 1811 by M. Courtois, saltpetre manufacturer at Paris. After ascertaining some of its properties he gave a quantity of it to M. Clement, who undertook to prosecute the investigation. On the 6th of December, 1813, M. Clement announced its existence to the Institute of Paris, and at the same time described some of its most remarkable properties. The investigation of it was immediately undertaken by M. Gay-Lussac, and prosecuted with his accustomed activity and sagacity. Sir H. Davy, who was at that time at Paris, began likewise to make experiments upon it, and his results were made known to the Royal Society before any of Gay-Lussac's papers were published, though the French chemist affirms that he preceded the British philosopher in demonstrating the peculiar nature of this substance. To these two gentlemen, especially to M. Gay-Lussac, we are indebted for our knowledge of most of the facts which have been ascertained respecting this singular substance.

Formation.   1. The process followed in France for obtaining iodine, is the following. Kelp, an alkaline substance obtained by burning sea weeds, is lixiviated with water till every thing soluble is taken up. The solution contains various salts; among others, hydriodates, which being only small in quantity, and very soluble, remain in solution after as much of the other salts as can be obtained by crystallization have been separated. The liquid, thus freed as much as possible from common salt, is put into a stone ware still, to which a glass capital is luted, the tube passing from which, terminates in two equal tureens, placed the one above the other. The liquid in the still is mixed with an excess of sulphuric acid, and heat is applied to the still. Violet coloured vapours pass over into the tureens, which are kept cool by cold water. These vapours condense on the sides of the pipe of the capital and the tureens. They constitute iodine. Various other acid fumes come over along with the iodine, namely, sulphuretted hydrogen, muriatic acid, and probably, also, a little chlorine and sulphurous acid. These vapours, no doubt, diminish the quantity of iodine obtained somewhat.

In this country (the suggestion originated with Dr. Wollaston) it is customary to add a quantity of black oxide of manganese to the concentrated liquid, at the same time with the sulphuric acid. This certainly increases considerably the product of iodine. But the French object to the addition, because it has a tendency to occasion the evolution of chlorine, which, combining with the iodine, would injure the product very materially. Mr. Macintosh of Glasgow, obviated this objection completely, by the following alteration of the process. He mixed the concentrated liquid with sulphuric acid, and boiled it some time. This drives off the whole muriatic acid and the sulphuretted hydrogen, and if too much sulphuric acid be not employed, there is no escape of violet coloured fumes. He then added the black oxide of manganese, and distilled as before directed. The iodine vapours were disengaged and condensed in the receiver.

To purify the iodine, it should be washed with a little water, then dried between folds of blotting paper. To obtain it quite pure, the best way is to distil it off a quantity of fused chloride of calcium.

2. Iodine thus obtained is a solid substance of a greyish black colour and the metallic lustre, having very much the appearance of native sulphuret of antimony. It is usually in scales of a greater or smaller size; but it may be obtained in crystals. And Dr. Wollaston has ascertained that its primitive form is an octahedron, somewhat similar to the primitive form of sulphur. The axes of this octahedron are to each other, as nearly as can be determined, as the numbers 2, 3, and 4.* Its specific gravity is stated by Gay-Lussac to be 4·948 at the temperature of 62°½.† I have repeatedly taken its specific gravity in as pure a state as I could get it in, by subliming it from chloride of calcium, and have always found it 3·0844, at the temperature of 60°. I do not know upon what this difference depends. I have tried both iodine made in this country, and in France; but the result was the same.

The smell of iodine is disagreeable and very similar to that of chlorine, though not nearly so strong. Its taste is acrid and hot, and continues for a long time in the mouth. Orfila has shown that when taken internally it possesses poisonous qualities.‡

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* Annals of Philosophy, v. 237. † Ann. de Chim. xci. 7.
‡ Toxicologie generale, tom. i. partie ii. p. 290.

In 1820, it was introduced into medicine by M. Coindet, a physician of Geneva, as a cure for the *goitre* or swelling of the glands of the neck, which is so common in some parts of Switzerland. It has been found, it is said, very efficacious indeed in removing that disease. The goitre being a disease almost unknown in Great Britain, our medical men have had no opportunity of trying it in that disease; but it has been employed in this country in various glandular diseases, and the general opinion seems to be, that it is a medicine of considerable activity and efficacy. It obviously possesses considerable stimulating properties.

3. Like chlorine it possesses the property of destroying vegetable colours; though it acts with much less intensity. It stains the hand of a deep yellow colour; but the stain in a short time disappears. Paper receives a permanent reddish brown stain, and is at last corroded by it.

4. It melts when heated to the temperature of $224\frac{1}{2}°$, and is volatilized under the common pressure of the atmosphere when raised to the temperature of $351\frac{1}{2}°$.* But if it be mixed with water and the liquid boiled, it may be distilled over with the water. When converted into vapour it has a very intense and very beautiful violet colour. It was from this colour that Gay-Lussac imposed on it the name of *iode*,† which Sir Humphry Davy changed into *iodine*, as better suited to our language. Its specific gravity when in the state of vapour is 8·678.‡

M. Dumas has repeated the experiment of Gay-Lussac, and obtained 8·716 for the sp. gravity.‖ The specific gravity deduced from theoretical considerations would be 8·8.§

5. When iodine is thrown into water the liquid acquires an orange yellow colour and the peculiar smell of iodine. But it continues tasteless, and holds in solution only about $\frac{1}{7000}$th

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* Gay-Lussac, Ann. de Chim. xci. 7. He fixes the temperature between 347° and 356°.

† From *ιωδης*, violet coloured.

‡ Gay-Lussac, Ann. de Chim. xci. 17.

‖ Ann. de Chim. et de Phys. xxxiii. 346.

§ It has been shown long ago by Dr. Prout and myself, that the specific gravity of all gases and vapours is either equal to the atomic weight, or to the atomic weight multiplied by ·5555 or by 0·2777. If the atomic weight of iodine be 16, then $16 \times 0·5555 = 8·8888$. If the atom weigh 15·75, then $15·75 \times 0·5555 = 8·8$. Now, the specific gravity deduced from that of hydriodic acid is 8·7882, which almost coincides with the theoretical quantity.

part of its weight of iodine. It is more soluble in alcohol, and still more in sulphuric ether.*

6. If a quantity of iodine be put into a thin glass tube shut at one end, and a bit of phosphorus be thrown on it, the two substances combine with great rapidity, and the evolution of a great deal of heat; but no light is visible. Sulphur and most of the metals likewise unite readily with iodine when the action of the two substances upon each other is assisted by heat. The new substances formed by this combination have received the name of *iodides.* Thus the beautiful red powder formed by the union of iodine and mercury is called *iodide of mercury.*

7. When any of these compounds is decomposed by the action of the galvanic battery the iodine attaches itself to the *positive* wire, and the substance with which it was united to the *negative* wire of the battery.

8. Iodine has the property of combining with starch, and of forming with it a compound which has a fine blue colour. This curious fact was first observed by MM. Colin and Gaultier de Claubry.† The easiest way of forming this compound is to triturate starch with an excess of iodine, to dissolve the mixture in potash, and then to add a vegetable acid. The *iodide of starch* falls down in the state of a fine blue colour. Stromeyer, Professor of Chemistry at Göttingen, has found that starch is a most delicate test of the presence of iodine in liquids. He affirms, that the starch acquires a perceptibly blue tinge, when the iodine does not exceed $\frac{1}{450000}$ of the liquid.‡

When we wish to employ starch as a test to discover the presence of iodine in any liquid, the best way is to add to it a little starch previously dissolved in water, and then to add to the solution a little sulphuric acid. If iodine be present the blue colour soon developes itself.

But it not unfrequently happens that substances exist in the liquid, and are disengaged by the sulphuric acid, which are capable of converting the iodine into hydriodic acid; as for example, sulphurous acid, sulphuretted hydrogen. In such cases the blue colour will either not appear, or it will speedily be destroyed; so that iodine may exist without being detected by this reagent. M. Balard has proposed a very simple remedy

* Gay-Lussac, Ann. de Chim. xci. 7.
† Ann. de Chim. xc. 92.
‡ Annals of Philosophy, vi. 312.

for such cases. After having added the sulphuric acid to the liquid, pour over it, taking care to avoid agitation, a little water impregnated with chlorine gas. This water having a less specific gravity will float upon the surface, and in a short time there will appear a deep blue zone at the point of contact between the two liquids. This blue portion though very thin is quite, visible; it may be made thicker by a very gentle agitation; but if the two liquids were mixed completely the blue colour would disappear altogether.[*]

9. Iodine has been detected in various sea plants by Gaultier de Claubry. He found it in fucus saccharinus, fucus digitatus, fucus vesiculosus, fucus serratus, fucus siliquosus, and fucus filum.[†] Davy found indications of the presence of iodine in the ashes of fucus cartilagineus, fucus membranaceus, fucus rubens, fucus filamentosus, ulva pavonia, and ulva linza.[‡]

Dr. Fyfe informs us that he found it in the ashes of fucus nodosus, fucus palmatus, fucus digitatus, the ulva umbilicalis, and the common sponge. But he could not detect it in sea water, nor in any land vegetable.[||]

Dr. Carter found it in the sulphureous mineral waters of *Castelnovo d'Asti*, in Piedmont, so celebrated for curing the goitre and other glandular affections.[§] M. Angelini had previously detected it in the mineral water of Sales, in the same country.[¶] M. Boussingault detected it in a yellowish liquid brought from the province of Antioquia in South America, and employed successfully as a cure for the goitre.[**] M. Krüger of Rostock, found it in the mother ley of the Sülzer salt spring in Mecklenburg Schwerin.[††] Dr. Tucker found it in the mineral spring of Bonnington near Leith;[‡‡] and Dr. Daubeny, Professor of Chemistry in Oxford, found it in various salt springs in England.

Iodine exists also in the mineral kingdom. Vauquelin found an iodide of silver in a mineral from Mexico which he analyzed. But he has given no description of the mineral, nor did he determine the proportion of the constituents.[|| ||]

[*] Ann. de Chim. et de Phys. xxviii. 178.
[†] Ann. de Chim. xciii. 75, 113.   [‡] Phil. Trans. 1814, p. 505.
[||] Edin. Phil. Journal, i. 254.
[§] Ann. de Chim. et de Phys. xxviii. 221.
[¶] Schweigger's Jahrbuch, vi. 319.   [**] Ibid. xxx. 91.
[††] Ibid. vii. 444.
[‡‡] Annals of Philosophy, (2d Series,) xii. 390.
[|| ||] Ann. de Chim. et de Phys. xxix. 99.

10. The atomic weight of iodine is investigated by determining the proportion of it which unites with the different bases. Gay-Lussac put a quantity of iodine and pieces of zinc with a sufficient portion of water into a glass flask, which was then hermetically sealed; it was then heated till the whole iodine had combined with the zinc, and had formed a colourless solution in the water. The weight of zinc and of iodine put into the flask being known, it was only necessary to weigh the residual zinc to know the proportion of that metal which had united with the iodine. The result was, that 100 parts of iodine were just saturated by 26·225 parts of zinc.* Hence, 4·25 parts of zinc would have combined with 16·2 of iodine.† Now, (4·25 being the atom of zinc,) it follows from this experiment, that 16·2 denotes the atomic weight of iodine. The experiment was repeated by Dr. Prout, who found that 50 parts of iodine combine with 12·9 of zinc.† But 12·9 are to 50 as 4·25 to 16·473, this makes the weight of the atom a little higher than it was found by Gay-Lussac.

I found that 20·5 grains of iodide of potassium, or 19·75 grains of iodide of zinc, are completely decomposed by 20·75 grains of nitrate of lead. From this I concluded that the atom of iodine weighs 15·5.‡

More lately Berzelius has made a set of experiments to determine the atomic weight of iodine, which he conducted with his usual attention to precision. He found that 5 grammes of iodide of silver, which he had purified with the utmost care, when heated and decomposed by a current of chlorine gas, formed 3·062 grammes of chloride of silver. By another experiment he found that 12·212 grammes of iodide of silver gave 7·4755 grammes of chloride of silver.|| Now, if we reckon the atom of silver to weigh 13·75, these experiments give 16·058 for the atomic weight of iodine.

My experiments were made with so much care that I have no doubts of their accuracy. But as I was not at the same pains with Berzelius in purifying my iodine, having merely sublimed it, there is a probability that it might not be quite free from all admixture of chlorine or bromine. On that account, I think that the mean between my result and Berzelius must come exceedingly near the truth. We may then

* Ann. de Chim, xci. 24.
† Annals of Philosophy, vi. 323.
‡ First Principles, i. 89.
|| Poggendorf's Annalen der Physik. xiv. 560.

consider the atom of iodine as weighing 15·75. I adopt this number more readily, because it agrees very nearly with the number deduced from the specific gravity of the vapour of iodine. The atomic weight deduced from 8·678, the specific gravity, according to Gay-Lussac, is 15·621. Dumas makes the specific gravity of the vapour 8·716, which gives us for the atomic weight of iodine 15·69. The atomic weight deduced from the specific gravity of hydriodic acid, as determined by Gay-Lussac, is 15·8. This last number is likely to be most accurate, because it was much easier to determine the specific gravity of hydriodic acid, which is a gas, than of the vapour of iodine. Now, 15·8 very nearly agrees with 15·75, which I therefore shall consider as the true atomic weight of that body.

Iodine has the property of combining with oxygen, chlorine, and bromine. It will be proper to describe the nature of these compounds.

Iodic acid.   1. The compound of iodine and oxygen was discovered in a separate state by Sir H. Davy, and constitutes one of the many striking analogies that exist between chlorine and iodine. It may be obtained by the following process. Put 40 grains of iodine into a thin long-necked receiver. Into a bent glass tube shut at one end put 100 grains of chlorate of potash, and pour over it 400 grains of muriatic acid, of the specific gravity 1·105. Then make the bent tube communicate with the receiver, and apply a gentle heat to it. Protoxide of chlorine* is generated. As soon as it comes in contact with the iodine a combination takes place, and two new substances are formed : 1. A compound of iodine and chlorine; 2. A compound of iodine and oxygen. When heat is applied to this mixture the compound of chlorine and iodine, which is volatile, flies off and leaves the compound of iodine and oxygen in a state of purity.† This substance possesses acid properties, and Gay-Lussac has proposed for it the name of *iodic acid*, which we shall adopt.

Its properties.   Iodic acid, when pure, is a white semi-transparent solid. It is destitute of smell, but has a strong astringent sour taste. Its specific gravity is considerable, for it sinks rapidly in sulphuric acid. When heated a little below the temperature at which

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* This gas ought to be made to pass through dry chloride of calcium (*muriate of lime*) before it comes in contact with the iodine, in order to deprive it of the water with which it is mixed when first generated.

† Davy, Phil. Trans. 1815, p. 204.

olive oil boils, it melts and is decomposed, being converted into iodine and oxygen gas. According to the mean of three experiments made by Sir Humphry Davy, a grain of iodic acid when decomposed gives out 176·1 grain measures of oxygen gas.* Now at the temperature of 60°, 176·1 grains of water are equal in bulk to 0·6968 cubic inch. But 0·6968 of a cubic inch of oxygen gas weighs 0·2411 grain. Therefore iodic acid must be a compound of

Iodine,   .   .   0·7589 or 15·75
Oxygen,   .   .   0·2411 or 5·003
————————
1·

Now 5 represents 5 atoms of oxygen. It is obvious from this that iodic acid is a compound of 1 atom iodine and 5 atoms oxygen. This was confirmed by Gay-Lussac, who analyzed the iodate of potash, and showed that iodic acid contains exactly 1 atom of iodine and 5 atoms of water.†

Thus iodic acid agrees exactly in point of composition with chloric acid.

Iodic acid is very soluble in water. When exposed to a moist atmosphere it gradually deliquesces. Its solution first reddens, and then destroys vegetable blues. It reduces other vegetable colours to a dull yellow. When this liquid is heated, the water gradually evaporates, and the acid acquires the consistence of a syrup. It then becomes pasty, and may be driven over unaltered, unless the heat applied be too great. In that case it acquires a purplish tint from a partial decomposition which sets a portion of the iodine free.

When mixed with charcoal, sugar, or other inflammable bodies, and heated, detonations take place. Its solution rapidly corrodes metallic bodies.

Sementini of Naples is of opinion that he has formed Iodous acid. another compound of iodine and oxygen, containing less oxygen, and called by him *iodous acid*, by the following process. Equal parts of chlorate of potash and iodine are to be triturated together till they form a yellow powder, in which no trace of the iodine can be detected. This is put into a retort and distilled by means of a spirit lamp. When the chlorate begins to part with its oxygen, dense yellow fumes arise, which condense in the receiver into a yellow fluid. This is the iodous acid.

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* Phil. Trans. 1815, p. 206.　　　　† Ann. de Chim. xci. 48.

Its taste is acid and astringent, and it leaves a burning taste on the tongue. It has a peculiar and disagreeable odour, somewhat resembling that of protoxide of chlorine. It is heavier than water; reddens vegetable blues, but does not destroy them. It is very soluble both in cold and hot water, and the solutions are yellow. It volatilizes rapidly at 212°; it is decomposed by sulphur, but not altered by charcoal; it is also decomposed by sulphurous acid; it sets fire to phosphorus and potassium. Nothing is known respecting the composition of this acid.*

M. Mitcherlich has announced another compound of iodine and oxygen, which he considers as containing less oxygen than either of the preceding, and analogous in its composition to hyposulphurous acid. But he has given no details sufficient to enable us to judge of the proportions of the constituents. This acid can only exist when combined with a base.†

2. The compound of iodine and chlorine was likewise first discovered by Sir H. Davy; but it was likewise examined by Gay-Lussac, before he was aware that it had been the object of the investigation of the British chemist. Davy has given the compound the name of *chloriodic acid*, which we shall adopt.

It is easily obtained. When a current of chlorine gas is passed into a vessel containing iodine, the combination instantly takes place. Chloriodic acid, when the iodine is saturated with chlorine, has a yellow colour, and becomes orange on fusion; but if there be an excess of iodine the colour is red.‡ To saturate the iodine in this way is attended with some difficulty; but it is easily accomplished by dissolving the red substance in water, and passing through it a current of chlorine gas till it be saturated. The solution of chloriodic acid obtained in this way is colourless, provided there be no excess of chlorine; but if there be, it has a yellow colour.||

It is not easy to determine the composition of this compound; because saturation is difficult, and it seems even to affect an overdose of iodine. Davy made two trials to determine the quantity of chlorine absorbed, by a given weight of iodine. The results were as follows: §

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* Annals of Philosophy, (2d Series) viii. 386.
† Ann. de Chim. et de Phys. xxxvii. 84.
‡ Davy, Phil. Trans. 1814, p. 498.   Gay-Lussac, Ann. de Chim. xci. 48.
|| Gay-Lussac, Ann. de Chim. xci. 50.   § Phil. Trans. 1814, p. 499.

(1.) 20 grains of iodine absorbed 13·125 cubic inches of chlorine gas = 10·195 grains. Now, 20 : 10·195 :: 15·75 : 8·029, which is the weight of chlorine, which, according to this experiment united with an atom of iodine.

(2.) 20 grains of iodine absorbed 9·6 cubic inches of chlorine = 7·474 grains. Now, 20 : 7·474 :: 15·75 : 5·887 = weight of chlorine united to an atom of iodine, according to this second experiment.

Now, 8·029, the weight of chlorine, which united with an atom of iodine, by the first experiment is only 0·971, or little more than ⅓th of an atom less than 2 atoms of chlorine. The number 5·887, indicated by the second experiment, is about ⅓th of an atom less than an atom and a half of chlorine. Shall we conclude from this that two different compounds were formed: the first a compound of two atoms of chlorine and 1 of iodine, and the second of 1½ atoms of chlorine and 1 atom of iodine? Or shall we consider the second experiment as indicating an imperfect combination?

Chloriodic acid is very volatile. When exposed to the air it deliquesces. Its solution in water, possesses acid properties. It gradually destroys vegetable blues. Even the solution of indigo in sulphuric acid is deprived of its colour by it. But it appears from the experiments of Gay-Lussac, that it is decomposed and converted into iodic acid and muriatic acid, (no doubt by the decomposition of water,) whenever we attempt to combine it with a base. This has induced him to doubt whether it possesses acid properties, and to suspect that it is decomposed whenever it is dissolved in water. On that account he has given it the name of *chloride of iodine.* But Davy's experiments seem to me to prove, that it dissolves in water without decomposition, and consequently that it is an acid.

3. We are indebted to M. Balard for every thing at present known respecting the combinations of bromine and iodine. Bromide of iodine. They seem to be capable of combining in two proportions. When the two bodies are placed in contact, in certain proportions we obtain a solid compound, which, when heated, gives out reddish brown vapours, condensing into small crystals of the same colour, and resembling fern leaves in appearance. A new addition of bromine transforms these crystals into a liquid resembling hydriodic acid, containing a great excess of iodine.

This liquid bromide is soluble in water, to which it commu-

nicates the property of destroying the colour of litmus paper, without reddening it. Alkalies poured into the solution, produce hydrobromates and iodates, as might have been expected from analogy.*

SECTION V.—OF FLUORINE.

History.   The mineral called *flour spar*, and in this country frequently distinguished by the name of Derbyshire spar, is so common in lead mines, and is so beautiful in consequence of its transparency, its fine colours, and the large size of its cubic crystals, that it must have early attracted the attention of mankind. There can be little doubt that it is mentioned both by Theophrastus and Pliny under the name of *false emerald* (ψευδης σμαραγδος.) In the time of Agricola it was employed as a flux for ores, and is mentioned by him under the name of fluor.† Its property of corroding glass, when mixed with sulphuric acid, was known at Nuremberg as early as 1670. The first attempt to ascertain the composition of this mineral was made by Margraf. His experiments were published in the Memoirs of the Berlin Academy for 1768; but he informs us that they had been made in 1764. He reduced the mineral to powder, mixed it with its own weight of sulphuric acid, and distilled it in a retort. He obtained a white saline sublimate, and remarked with surprise, that the retort was corroded into holes in several places.‡ In the year 1771, Scheele published a set of experiments on fluor spar, in the Memoirs of the Academy of Sciences of Stockholm. He showed that the mineral was a compound of lime, and of a peculiar acid, to which he gave the name of *fluoric acid*. He determined the properties of this acid, and showed it to differ from every other previously known.‖ Dr. Priestley found that the acid, when obtained by Scheele's process, is a gas possessed of peculiar properties which he investigated and described.¶

It was shown by Wiegleb** and Bucholz,†† and still more completely by Meyer,‡‡ that the fluoric acid of Scheele contained silica as a constituent, and Dr. John Davy ascertained the proportion of fluoric acid and of silica, that exist in the

* Ann. de Chim. xxxii. 372.
† Georg. Agricolæ Bermapnus, p. 458; Basil edition of 1558.
‡ Collection Academique, xvi. 281.
‖ Memoires de Chymie de M. C. W. Scheele, i. 1.
¶ Priestley on Air, ii. 339.
** N. Entd. in d. Chemie. Th. i. p. 1—15   †† Ibid. Th. iii. p. 50.
‡‡ Schriften der Berliner Gesellschaft, naturf. Freunde, b. ii.

acid of Scheele,[*] and demonstrated that it is a peculiar compound of fluoric acid and silica, in which the constituents always exist in the same proportions. Gay-Lussac and Thenard, in their Recherches Physico-chimiques,[†] published in 1811, pointed out a method of preparing pure fluoric acid, and were the first to determine its properties. It may be procured in the following manner.

A retort of pure lead must be procured, composed of two pieces which slip into each other. To this retort must be adapted a leaden receiver. This apparatus is represented in the figure in the margin. Take any quantity of pure white fluor spar, reduce it to a fine powder, and put it into the retort, then mix it well with twice its weight of concentrated sulphuric acid. Lute the joining of the retort and the beak where it enters the receiver, with clay, then apply a moderate heat to the retort, taking care that it is not so great as to fuse the lead. The receiver is to be surrounded with a mixture of common salt and snow. The fluoric acid is disengaged, and collected in the receiver in a liquid state.[‡] This acid possesses the following properties.

At 32° it is a colourless liquid like water. It does not congeal though cooled down to — 4°, and it continues liquid at the temperature of 60°. Its boiling point has not been determined, but it is low. When exposed to the air it smokes violently, giving out a smell similar to that of muriatic acid, but much stronger. It is very speedily dissipated in open vessels, and can only be preserved in metallic vessels. The best adapted for the purpose are those which are composed of pure silver, and they must have a silver stopper, which should be air tight.

When this acid is as concentrated as possible, it would appear from the experiments of Davy, that it contains no water. Its specific gravity is then 1·0609. When united to a certain portion of water, its specific gravity becomes 1·25.[§] When a drop of it is let fall into water, a hissing noise takes place similar to what is heard when a red hot iron is plunged into that liquid. When a few drops of water are let fall into fluoric acid it enters into ebullition. A great deal of water may be added without destroying its fuming property. Care must be taken not to breathe the fumes of this acid, as they

* Phil. Trans. 1812, p. 352.   † Vol. ii. p. 1.
‡ Recherches Physico-chimiques, ii. 2.
§ Davy, Phil. Trans. 1813, p. 266.

are very deleterious. When a drop of it falls upon the skin, it acts as a powerful corrosive, and occasions a sore which does not soon heal.

When this acid comes in contact with glass, it immediately corrodes it, and is converted into a gaseous body, known by the name of fluosilicic acid.* This acid combines readily with the different bases, and forms a genus of salts called *fluosilicates.* Berzelius has, in 1823-4, published an important series of experiments, chiefly upon the combinations of fluoric acid, the new acids which it thus forms, and the salts which their numerous acids are capable of constituting.†

Atomic weight.

The first set of accurate experiments to determine the atomic weight of this acid, was by Sir H. Davy. He found that 100 gr. of pure *fluor spar*, when decomposed by sulphuric acid, formed 175·2 grains of sulphate of lime. Now the lime in 175·2 gr. of this sulphate, amounts to 72·141 grains. If, therefore, fluor spar be a compound of fluoric acid and lime, it is obvious that its constituents must be

Fluoric acid 27·850 or 1·351
Lime   72·141 or 3·5

This would make the atom of fluoric acid 1·351. Berzelius, in his first experiments, obtained a result different from that of Davy, but he has since corrected some errors into which he had fallen, and his analysis of fluor spar, agrees almost exactly with that of Davy.‡

I found that 5·25 grains of fluate of soda, dried in a red heat, just saturate all the lime in 6·25 grains of pure carbonate of lime, dissolved in muriatic acid, and rendered neutral by evaporation to dryness and solution in water. Now 6·25 grains of carbonate of lime are equivalent to 3·5 grains of lime. And the muriatic acid which saturates 3·5 lime, will just saturate 4 of soda. Hence the 5·25 of fluate of soda must have contained 4 soda. The weight of the fluoric acid then must have been 1·25. And 1·25 fluoric acid must just saturate 3·5 lime. Hence the atomic weight of fluoric acid must be 1·25.§

It had been the general opinion of chemists that fluoric acid is a compound of an unknown basis and oxygen, and this opinion was adopted and maintained by Gay-Lussac and Thenard, in their Recherches Physico-chimiques. But in

* This acid will be described in a subsequent part of this work.
† Kongl. Vetensk. Acad. Handl. 1823, p. 284; 1824, pp. 46, 278.
‡ Annals of Philosophy, (2d series) viii. 338.
§ First Principles, ii. 168.

the year 1810, M. Ampere, who had adopted the views of Sir Humphry Davy, respecting *chlorine* and the composition of *muriatic acid*,* was led to compare together the fluoric and muriatic acids; and to draw similar conclusions with respect to the composition of both. Now the base of muriatic acid is *hydrogen*, and the hydrogen in it is combined with *chlorine*, a supporter of combustion. Therefore, supposing the composi- tion of both similar, fluoric acid must likewise be a compound of *hydrogen*, and an *unknown* supporter of combustion. This view of the subject he communicated to Sir H. Davy in 1810, who at first was rather inimical to the opinion; but upon considering the subject, he was gradually led to change his notions,† and at last became a strenuous supporter of the hypothesis. He published two papers in succession on the subject containing each many highly interesting experiments, and ingenious views and deductions;‡ but he was unable to obtain the supposed supporter of combustion, in fluoric acid, in a separate state. I think, however, that the reasons adduced for its existence are sufficiently plausible, and on that account have been induced to give it a place among the supporters of combustion. Davy has given it the name of *fluorine*, which we shall adopt.§ I shall now state the evidence for the existence of fluorine that has been brought forward by the experiments of Davy. I shall be under the necessity of making use of many substances which have not yet been described. Beginners, therefore, will find it convenient to peruse the two following chapters before they read the remainder of this section.

1. When fluoric acid and potassium are brought into con- tact, a violent action takes place; a solid white substance is formed, and a quantity of hydrogen gas is discharged. If the fluoric acid be free from water, it is obvious that this result

* Namely, that it is a compound of equal volumes of chlorine and hydrogen gases.

† Ann. de Chim. et Phys. ii. 21.

‡ Phil. Trans. 1813, p. 263; and 1814, p. 62.

§ Ampere has given it the name of Phthorine, (Phthore) from the Greek word φθοριος, *destructive*. Ann. de Chim. et Phys. ii. 24. But it is quite evident that this new name cannot be adopted. There would be no end to names if every person at pleasure could coin new ones. The reason assigned by him for contriving this new name, namely, that he was the original starter of the hypothesis, is not valid. Mr. Gregor was the discoverer of *titanium*; yet the name imposed by Klaproth has kept its place, and even borne down the name *Menachane*, previously applied by Kirwan. Davy informs us that Ampere himself originally suggested the term *fluorine*.

is best explained by supposing the fluorine and the potassium to combine and form the solid substance, while the hydrogen, previously united to the fluorine in the acid, makes its escape in the form of gas. But it requires to be ascertained whether fluoric acid of the specific gravity 1·0609 contains any water. For this purpose Davy put a quantity of it into a platinum tray, and placed it in contact with ammoniacal gas till it was saturated with that alkali. By this means a white salt was formed, known by the name of fluate of ammonia. When any acid that contains water is combined in this manner with ammoniacal gas, if we heat the salt formed, water is always disengaged. Thus sulphuric acid, or nitric acid, or phosphoric acid, when saturated with ammoniacal gas and heated, give out always abundance of water. But fluate of ammonia when thus treated gave out no water.* Hence we have no evidence that fluoric acid contains any water.

2. Muriatic acid is a compound of chlorine and hydrogen gas, the combination of it with ammonia is called *muriate of ammonia*. When potassium is heated with muriate of ammonia, chloride of potassium is formed, and a quantity of gas disengaged. This gas is a mixture of ammonia and hydrogen, and consists of two volumes of ammonia, and one volume of hydrogen gas. Now when fluate of ammonia is treated with potassium, a similar effect is produced. A white saline substance is formed, and gas is evolved, consisting of ammonia and hydrogen, in the proportion of two volumes of the former to one volume of the latter.† Now since the effects in these two cases are similar, the fair inference seems to be that the products are similar. The dry substance is probably a fluoride of potassium, while the hydrogen was previously united with the fluorine, and constituted with it fluoric acid.

3. When fluoric acid is exposed to the action of galvanism, hydrogen gas is given out at the negative wire, and the positive wire (supposing it platinum) is coated with a chocolate powder.‡ When muriatic acid is treated in the same way it is decomposed, its hydrogen being given off at the negative wire, while its chlorine unites with the positive wire. Is it not probable then that the chocolate powder is a compound of fluorine and platinum?

4. If fluate of silver or fluate of mercury be exposed to the action of chlorine, and heated in glass vessels, chloride of silver

* Davy, Phil. Trans. 1813, p. 268. † Ibid. p. 269. ‡ Ibid. p. 271.

or of mercury is formed, while the vessel is corroded, and a
quantity of fluosilicic acid gas mixed with oxygen evolved.*
Is it not probable that in this case the fluorine is disengaged,
that it immediately acts upon the silica in the glass, disengaging
its oxygen and forming fluosilicic acid, which may be considered
as a compound of fluorine and silicon?

Various attempts were made to obtain the fluorine in a sepa-
rate state, by repeating this experiment in vessels of platinum
and silver: but in both cases it combined with the metal.   So
that it seems fluorine has the property of combining with all
bodies that can be employed as vessels.   This precludes the
possibility of obtaining it in a separate state.

These reasons have been still farther confirmed by various
compounds of fluorine, discovered by more recent experiments,
and which will be described in the subsequent part of this work.
Now it is obvious that if fluor spar be a compound of *fluorine* and
calcium, the weight of an atom of it will be 2·25.   For lime is
a compound of 1 atom calcium = 2·5 and 1 atom oxygen = 1.
And as the calcium during the analysis is converted into lime,
it is obvious that the weight of the fluorine, estimated merely
by the loss of weight, must be underrated by the quantity of
oxygen which has united to the calcium or 1.   Therefore fluor
spar is a compound of

$$1 \text{ atom fluorine} = 2·25$$
$$1 \text{ atom calcium} = 2·5$$
$$\overline{}$$
$$4·75$$

Such are the properties of the supporters of combustion, as
far as they can be detailed in this early part of the work.   The
numerous compounds which they form with the other simple
bodies, will fall to be described in the subsequent chapters.
They are probably capable of uniting with every one of the
other simple bodies.   When they unite with certain simple
bodies, they constitute *acids*, when with others *alkalies* or *bases*.
While some of the compounds possessing neither *acid* nor *alka-
line* qualities, may be called *neutral.*   Those acids and bases,
containing the same supporter, are capable of uniting with each
other, and of forming salts without decomposition.   But when

* Davy, Phil. Trans. 1813, p. 275.

an acid containing one supporter, is brought into contact with a base containing another supporter, it is more rarely that they combine. Much more frequently they mutually decompose each other.

Thus there exist *oxygen acids,* *chlorine acids,* *bromine acids, iodine acids,* and *fluorine acids,* and the same number of sets of bases. We have oxygen salts, chlorine salts, bromine salts, iodine salts, and fluorine salts. Berzelius has shown likewise, that *sulphur* has the property of combining with the other simple bodies, in the same way as the supporters do, and of forming *sulphur acids* and *sulphur bases,* which readily combine with each other and form what may be called *sulphur salts.** He assures us that selenium and tellurium agree with sulphur in this respect; that these bodies unite with the other simple substances, forming acids and bases capable of combining with each other, so that a class of selenium salts and of tellurium salts, may also be formed. Sulphur, selenium, and tellurium, might, therefore, be classed along with the supporters; but their analogies with the acidifiable bases are so strong, and so close, that it seems more advisable to place them in that set of simple bodies.

The atomic weights of the supporters are as follows.

Oxygen	. .	1
Fluorine	. .	2·25
Chlorine	. .	4·5
Bromine	. .	10
Iodine	. .	15·75

Chlorine is just double the weight of fluorine, and iodine just 7 times the weight of the same atom.

It is probable that fluorine is still more negative than even oxygen, which excels all the other supporters in this respect. But as fluorine has not yet been obtained in a separate state, our conclusions can only be supported by conjecture and analogical reasoning.

* Kong. Vetensk. Acad. Handl. 1826, p. 332.

CHAP. II.

OF THE SIMPLE ACIDIFIABLE BASES.

THE simple acidifiable bases at present known, are the following.

1 Hydrogen	7 Sulphur	13 Uranium
2 Azote	8 Selenium	14 Molybdenum
3 Carbon	9 Arsenic	15 Tungsten
4 Boron	10 Antimony	16 Titanium
5 Silicon	11 Tellurium	17 Columbium.
6 Phosphorus	12 Chromium	

The first two of these bodies, hydrogen and azote, are gases, which have never been reduced to a liquid or solid state. Carbon, boron, and silicon, are black, fixed powders, which have neither been melted nor volatilized. Phosphorus, sulphur, and selenium, are solids easily fused and volatilized by heat. Arsenic, antimony, and tellurium, are metals easily fusible and volatilized. The last six are difficultly fusible metals, which have been hitherto obtained in the metallic state, only, in minute quantities.

I shall treat of these acidifiable bases in their order, in the 17 following sections.

SECTION I.—OF HYDROGEN.

Pure hydrogen can scarcely be said to exist in an insulated state, but it constitutes a part of water from which it may be easily evolved by very simple processes. Being sometimes in a state of combination emitted in considerable quantities from the surface of the earth in mines, it had occasionally attracted the notice of observers.* Mayow,† Boyle,‡ and Hales,§ procured it in considerable quantities, and noted a few of its mechanical properties. Its combustibility was known about the beginning of the 18th century, and was often exhibited as a curiosity.‖ But Mr. Cavendish ought to be considered as its real discoverer; since it was he who first examined it, who pointed out the difference between it and atmospheric air, and who ascertained the greatest number of its properties.¶ The properties and compounds into which it enters, were afterwards

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* See an instance related in Phil. Trans. 1667, No. 26, p. 452.
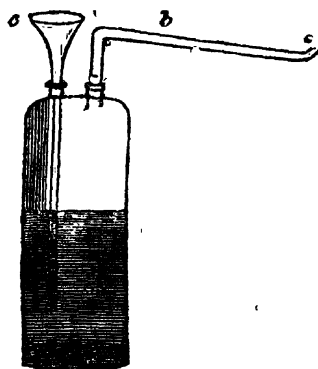† Tractatus Quinque, p. 163. ‡ Shaw's Boyle, iii. 21. § Statics, i. 221.
‖ Cramer's Elementa Docimasia, i. 45. This book was published in 1739.—Wasserberg relates a story of an accidental explosion which terrified Professor Jacquin's operator. Wasserberg's Institutiones Chemiæ, i, 184.
¶ Phil. Trans. 1766, vol. lvi. p. 141.

examined by Priestley, Scheele, Lavoisier, Gay-Lussac, and Humboldt, Dalton, Henry, Berzelius, and Dulong, and various other chemists.

Hydrogen may be procured with great ease by the following simple process. Into a small retort, or a small glass jar with two mouths, as in the margin, put a number of small pieces of zinc, and a quantity of water sufficient to fill it about half full. Through a perforated cork fitted into one of the mouths of the glass, let a glass tube pass, grasped so tightly by the cork that no air can pass between them. This tube passes to near the bottom of the vessel. Its lower extremity terminates in a small opening, but its upper extremity is widened out into a funnel-shape. Into the other mouth of the bottle is fixed, by means of a perforated cork, the bent tube *b*, the extremity of which dips into a water trough under the mouth of a glass cylindrical receiver filled with water and inverted over the shelf of the trough. Sulphuric acid is poured into the funnel-shaped extremity of the glass tube *c*. It sinks by its weight to the bottom of the vessel *a*, mixes with the water, and begins to act on the zinc. Air bubbles separate in great abundance and rise to the top of the vessel *a*. These air bubbles constitute hydrogen gas. We must not begin to collect this gas till it has had time to displace all the common air which occupied the upper part of the vessel *a* and the bent tube *b*. When we think that enough has been disengaged to get rid of all that air, the bent tube *b* is brought under the inverted jar, the hydrogen gas passes along it, rises to the top of the inverted jar, and gradually fills it. Sulphuric acid is poured occasionally when the effervescence begins to flag through the tube *c* into the vessel *a*.

Unless the zinc, the water, and the sulphuric acid, be pure, the hydrogen gas thus generated is not free from all admixture of foreign matter. Even, when all the ingredients employed are pure, there is reason to suspect from the colour of the gas when burning, that it is not absolutely free from all admixture of zinc. However, the quantity of that metal in such cases must be exceedingly minute. Zinc is seldom or never perfectly pure. It usually contains traces of sulphur, sometimes

of arsenic, and sometimes of charcoal. On this account hydrogen gas often contains a little sulphur, a little arsenic, and according to Mr. Donovan, a little carbonic acid.* The sulphur and arsenic, and also the carbonic acid, if present, may be removed by passing the hydrogen gas through a glass tube, containing pieces of caustic potash.

Hydrogen gas may be obtained also, by a similar process; but substituting iron filings instead of zinc. In that case the gas is much less pure than when zinc is employed. It then contains sensible traces of charcoal; and likewise an oily matter, which may be separated by passing the gas through alcohol. When the alcohol thus treated, is mixed with water, and set aside for some days, the oil separates, and may be collected in sensible quantities. This fact was first ascertained by Prout.

1. Hydrogen gas thus obtained and purified, possesses the mechanical properties of atmospherical air, and like that fluid is destitute of colour, taste, and smell. When obtained by means of iron filings, the smell is bituminous and disagreeable. It is owing to the oily matter, the vapour of which, in that case, is mixed with it. When zinc is used, the smell is much weaker, but still sensible. But when properly purified, the smell is destroyed. Hydrogen gas. evolved by putting the amalgam of potassium into pure water, has, according to Berzelius, no smell; but if an acid or sal ammoniac be added to the water, it acquires the same smell as when it is obtained from common zinc.

Sensible properties.

2. It is the lightest gaseous body with which we are acquainted. Biot and Arago found it 0·0732, that of air being 1.† I prepared it from distilled zinc, pure sulphuric acid, and distilled water, and washed it carefully before weighing it. I found the specific gravity at 60°, and when the barometer stands at 30 inches, to be 0·0693, reckoning air 1. Berzelius and Dulong purified hydrogen gas with great care, and found the specific gravity of it, in that state, between 0·0688, and 0·0689.‡ The difference between this determination and mine is rather more than $\frac{1}{200}$dth part. I am disposed to consider the true specific gravity to be 0·0694, that of air being 1. This is the specific gravity deduced by Dr. Prout, from the specific gravity of ammoniacal gas.§ The specific gravity of this gas,

Specific gravity.

* Phil. Mag. xlviii. 138.   † Mem. de l'Institut. 1806, p. 320.
‡ Ann. de Chim. et de Phys. xv. 386.
§ Annals of Philosophy, vi. 322.

as determined by Davy, is 0·590164; while I found it from a mean of three trials 0·59031. The mean of these two numbers, which cannot differ far from the truth, is 0·590237. Now ammoniacal gas is a compound of 3 volumes hydrogen gas, and one volume of azotic gas, condensed into two volumes. Hence (if the specific gravity of hydrogen gas be x) we have

$$\frac{3x + 0.9722}{2} = 0.590237,$$ which gives us $x = 0.0694$.

If 1·1111 be the specific gravity of oxygen gas, and 0·0694 that of hydrogen gas, then the former is exactly 16 times heavier than the latter. Now, by the analysis of water by Berzelius and Dulong, we have the weight of a volume of hydrogen to a volume of oxygen gas, as 1 to 16·014, which differs less than $\frac{1}{1000}$th part from the ratio of 1 to 16. Such a deviation being far within the limits of error from experiment, it seems to savour of affectation to assume any other ratio.*

Employed to elevate balloons. In consequence of this extreme lightness of hydrogen gas compared with common air, it is employed to elevate weights and raise them to a considerable height in the atmosphere by means of air balloons. These are large bags of silk covered with varnish to make them air tight, and filled with hydrogen gas. Let us suppose the balloon to be a sphere of varnished silk, 10 feet in diameter. Its cubic contents will be nearly 423·6 cubic feet. Now, 423·6 cubic feet of air weigh about $32\frac{1}{2}$ lbs. avoirdupois. But the same weight of hydrogen gas (supposing it pure, will weigh no more than 2 lbs. If therefore the silk bag containing the gas weigh less than 30 lbs., it will not only float, but actually ascend in the air, and it will ascend the higher the greater the difference between the weight of the balloon and that of the surrounding air. A cubic foot of air weighs about 538·18 grains. And 3000 cubic feet weigh about 231 lbs.; while the same volume of hydrogen gas would only weigh 14·4 lbs. It would therefore be sufficient to elevate a very considerable weight. But the gas with which balloons are filled, is obtained usually from iron turnings, and

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* If we admit the specific gravities of oxygen, azote, and hydrogen, to be as follows :

Oxygen,	.	.	.	1·1111
Azotic,	.	.	.	0·9722
Hydrogen,	.	.	.	0·0694

Then oxygen is precisely 16 times, and azotic gas 14 times heavier than hydrogen.

is much heavier than pure hydrogen gas, seldom lighter than
one-fifth the weight of common air, and sometimes even heavier
than that.   On this account, the volume of the balloon requires,
to be considerably greater than would be necessary, if the gas
could be employed in a state approaching to purity.

3. It refracts light much more powerfully than any other
gaseous body, if we take into account its small specific gravity.
According to the experiments of Dulong, its refracting power
is 0·470, that of air being represented by 1.*

4. As the intensity of sound is diminished by the rarefaction Diminishes
sound.
of the medium in which it is produced, we would naturally
expect it to be feebler in hydrogen gas than in common air.
But Mr. Leslie has shown that the diminution is much greater
than was to have been expected.   He put a piece of clock-
work, by which a bell is struck every half minute within the
receiver of an air-pump, and after exhausting the air 100
times, introduced hydrogen gas into it.   But the sound, instead
of being augmented, was much feebler than in air rarefied 100
times.   A mixture of hydrogen gas with common air has a
great influence in blunting the sound.   If half the volume of
atmospherical air be extracted, and hydrogen gas admitted to
fill the vacant space, the sound will now become scarcely
audible.†

It is well known that sound moves, at least, thrice as fast in
hydrogen gas as in air.

5. All burning substances are immediately extinguished by
being plunged into this gas.   It is incapable therefore of sup-
porting combustion.

6. When animals are obliged to breathe it, they soon die.
The death is occasioned merely by depriving the animal of
oxygen.   The animal dies precisely as it would do if plunged
under water.

When a mixture of hydrogen and oxygen gases is made in Occasions
sleep.
the same proportions as common air, substituting hydrogen for
azotic gas, animals put into it breathe without any inconveni-
ence.   But from the trials of Messrs. Allen and Pepys, it
appears to have the curious property of throwing the animal
into a profound sleep.

7. Hydrogen gas is not sensibly absorbed by water though Not absorbed
by water.
left in contact with it.   When water has been previously
deprived of its air by boiling, it absorbs, according to the

* Ann. de Chim. et de Phys. xxxi. 166.
† Annals of Philosophy (2d Series), iv. 172.

experiments of Dr. Henry, 1·53 per cent. of hydrogen gas.[*] Saussure states that water absorbs 4½ per cent. of it, and alcohol 5·1 per cent.[†] But his experiments probably err in giving a result rather above the truth.

8. No pressure hitherto applied, though amounting to fully 1000 atmospheres, has had any sensible effect in condensing hydrogen gas or reducing it to a liquid state. It is probably the most difficultly condensible of all the gases.

II. Hydrogen has the property of combining with all the supporters of combustion. The compound which it forms with oxygen is *water*. With chlorine it forms *muriatic* or *hydrochloric acid;* with bromine *hydrobromic acid;* with iodine *hydriodic acid;* and with fluorine *hydrofluoric acid.*

Combines with oxygen.

1. When a lighted candle is brought to the mouth of a phial filled with hydrogen gas, it burns with a flame scarcely perceptible in daylight, and having a white or bluish white colour if the gas be pure; when tinged red, or green, or yellow, these colours indicate the presence of some foreign substance in the gas.

If pure oxygen and hydrogen gas be mixed together, they remain unaltered; but if a lighted taper be brought into contact with them, or an electric spark be made to pass through them, they burn with astonishing rapidity, and produce a violent explosion. If these two gases be mixed in the proportion of one part in bulk of oxygen gas and two parts of hydrogen gas, they explode over water without leaving any visible residuum; the vessel in which they were contained (provided the gases were pure) being completely filled with water. This important experiment was made by Scheele;[‡] but for want of a good apparatus he was not able to draw the proper consequences. Mr. Cavendish made the experiment in dry glass vessels with all that precision and sagacity which characterise his philosophical labours, and ascertained, that after the combustion there was always deposited a quantity of water equal in weight to the two gases which disappeared. Hence he concluded that the two gases had combined and formed this water. This inference was amply confirmed by the subsequent experiments of Lavoisier and his friends. Water, then, is a compound of oxygen and hydrogen, united in the proportion of one volume of oxygen to two volumes of hydrogen.

And forms water.

[*] Phil. Trans. 1803, p. 274.   [†] Annals of Philosophy, vi. 340.
[‡] Scheele on Air and Fire, p. 57; and Crell's Annals, iii. 101. Engl. Trans.

But the specific gravity of oxygen gas is 1·1111, and that of hydrogen gas 0·0694. So that oxygen gas is 16 times heavier than hydrogen gas. Therefore water is composed by weight of

| Oxygen, | . | . | 8 | 1·· |
| Hydrogen, | .. | . | 1 | 0·125 |

If therefore we suppose water to be composed of one atom of oxygen and one atom of hydrogen, and represent the weight of an atom of oxygen by 1, the weight of an atom of hydrogen will be 0·125.

A stream of hydrogen issuing from a tube may be set on fire by bringing in contact with it an iron just visibly red hot. At lower temperatures it does not burn with flame; but silently combines with the oxygen of the atmosphere, and is converted into water.

Davy found that a mixture of two volumes hydrogen and one volume oxygen, would not burn by an electric spark when expanded to 18 times their natural volume, but when the tube containing the gases was heated nearly to redness and an electric spark passed, a feeble flash of light was visible indicating a combustion.

When 100 volumes of air are mixed with 42 volumes of hydrogen gas, and an electric spark passed through the mixture, a detonation takes place, the oxygen of the air is consumed, and the residue consists chiefly of azote. This is the easiest method of analyzing air. Gay-Lussac and Humboldt found, that when the experiments were made with the requisite accuracy, the volumes of oxygen gas in 100 volumes of air indicated, are almost exactly 21 volumes. As water is formed by the union of 2 volumes hydrogen and 1 volume of oxygen, the diminution of bulk divided by 3, gives the volume of oxygen gas in the mixture. I made a set of experiments with every attention to accuracy that I could think of, in order to obtain correct results. The air employed was collected over a green field at some distance from houses, and the hydrogen gas was prepared by means of distilled zinc, pure sulphuric acid and distilled water. The retort employed was completely filled with the mixture, and the hydrogen for the analysis of the air was used as it was issuing out of the beak of the retort without being allowed to stand over water. The result of these experiments was as follows.

Unless we mix 42 volumes of hydrogen gas with 100 of air

the combustion is incomplete, a little oxygen escaping the action of the hydrogen.   Thus a mixture of 100 volumes air and 40 hydrogen being fired, the diminution of bulk was only 57, indicating only 19 per cent. of oxygen in the air.   A mixture of 100 volumes air and 42 hydrogen being fired, the loss of bulk was precisely 60 volumes in three experiments; indicating 20 volumes of oxygen.   When the quantity exceeds 42 volumes of hydrogen, the loss of volume after firing constantly increases with the hydrogen.   When we mix 100 volumes of air with 100 of hydrogen, the diminution of bulk by firing such a mixture, was 64 volumes, indicating $21\frac{1}{3}$ volumes of oxygen.*   As the diminution of bulk depends upon the proportions in which the air and hydrogen are mixed, it is clear that this method alone is not sufficiently precise to give us the volume of oxygen in common air.   I therefore left a hundred volumes of air standing over mercury to the action of phosphorus during two days in the summer of 1824. ' The diminution of bulk after washing the residue in water was considered as the oxygen abstracted by the phosphorus.   The mean of ten experiments made in this way gave the composition of common air.

Oxygen,	. .	20·0265 volumes
Azotic,	. .	79·9735
		————
		100

This differs by little more than $\frac{1}{1000}$th part from 20 volumes oxygen and 80 azote, and as my measures were not minute enough to enable me to determine within $\frac{1}{1000}$th part of the bulk, I consider myself entitled to consider the volume of oxygen in common air, as sensibly 20 per cent.†   Hence it is obvious, that in order to deprive 100 volumes of air of the whole of their oxygen (exactly) by combustion, we must mix them with 42 volumes of hydrogen gas, which is a redundancy of $\frac{1}{21}$ part of the whole.   If we employ less, some oxygen remains unconsumed; if we employ more, some ammonia is formed, which diminishes both the residual hydrogen and the azote, and thereby makes the loss of bulk, and consequently the oxygen too high.

If we put a few pieces of zinc with dilute sulphuric acid into a common eight ounce phial, furnished with a perforated

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* First Principles, i. 96.   † Ibid. i. 98.

cork, through which a small glass tube passes, having its upper extremity drawn into a capillary bore, the hydrogen gas issues through this tube at first with great violence; but when the action of the acid on the zinc diminishes, the gas issues more slowly, and in smaller quantities.   When this is the case, if we set fire to the gas as it issues, and then slip the glass tube *a* over it, pretty loud sounds are produced. These sounds vary with the size and length of the tube, and with the height of the tube *b*, in the tube. The most musical notes are produced when the tube *a* is about 3 feet long, and rather narrow, and when the tube *b* does not pass higher up than an inch or two.   These tones were first produced by Dr. Higgins, in 1777, while exhibiting the formation of water, by the combustion of hydrogen gas.*   The cause of these sounds was first explained by Mr. Faraday, who showed that small successive explosions take place in the tube, by the combustion of mixed portions of air and hydrogen. The vibrations produced by these explosions produce the sound.

Produces musical tones.

a

b
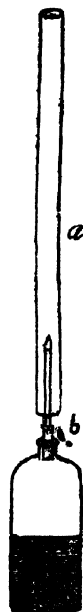
When a mixture of oxygen and hydrogen gases is set on fire, they burn with very little light; but produce a most intense heat.   This mixture was first employed as a blow-pipe, by Dr. Hare of Philadelphia, about the year 1800 or 1801, and he succeeded, by means of it, in fusing the most refractory mineral substances.†   More lately it was revived by Dr. Clarke, who, at the suggestion of Mr. Newman, introduced a mixture of the two gases into Brooke's blow-pipe, and condensed them, and then set fire to the mixture issuing out of a capillary tube.   The results obtained by him, were nearly the same as those which had been already made known by Dr. Hare.   I contrived an oxygen and hydrogen blow-pipe, in the year 1801, and made many experiments on its powers; but as almost all my results had been anticipated by Dr. Hare, I never thought it worth while to give any of them to the public.   My trials were confined chiefly to the metals, all of which, that I had an opportunity of trying, I found I was able to melt by this powerful instrument. I have been annually in the habit of exhibiting the effects of this blow-pipe to my students, and as the instrument is simple,

Oxy-hydrogen blow-pipe.

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* Nicholson's Journal, i. 130.
† Ann. de Chim. xlv. 113.
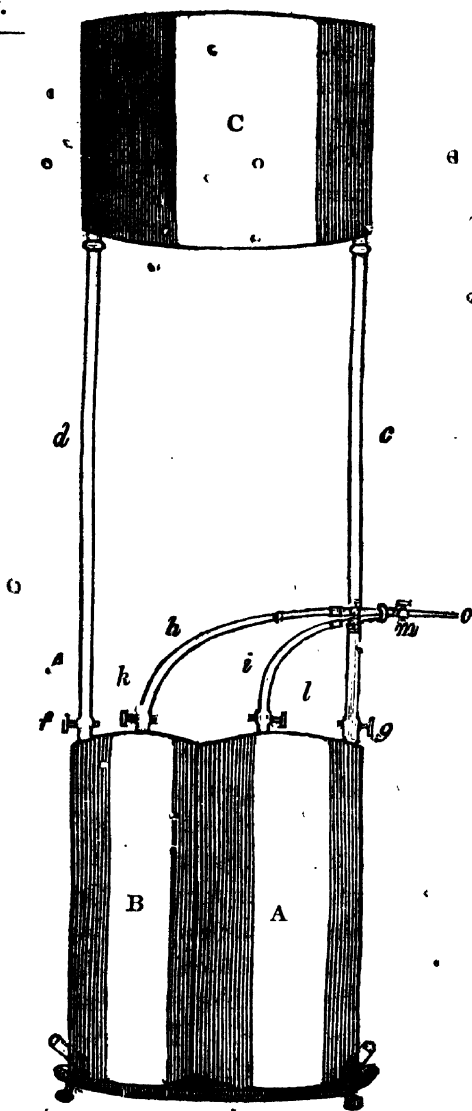
and has not hitherto been described, it may be worth while to exhibit an outline of it here.

A and B are two air-holders, of which A has double the capacity of B. From each of these air-holders proceeds the tubes d and e, about 5 feet long, and terminating in the bottom of the open vessel C, which is capable of holding as much water as will fill the two vessels, A and B, completely. d and e have the stop-cocks f and g, and they are screwed into the top and bottom of B, A, and C, by means of right and left handed screws. From the top of A and B proceed the tin tubes h and i, having the stop-cocks k and l, and terminating each by grinding into the common stop-cock m. The air-holder A is filled with hydrogen gas, and the air-holder B with oxygen gas. The vessel C is filled with water. By opening the stop-cocks f and g, the water runs down into the gas-holders A and B, and compresses the gases. When the stop-cocks k, l, and m are turned, the gases are forced along the tin tubes, and mixing together in the common stop-cock tube m, issue at the point o with great violence. As they issue from o, they are set on fire, and form a jet of white flame scarcely visible. The hydrogen gas would issue in too great proportion; but this is easily regulated by opening the stop-cocks k, l, more or less respectively, till the flame of the jet is brought to a very small diameter, and becomes white. The substances to be acted on are merely placed within this flame. Earths and powders I usually put into the mouth of a tobacco pipe. The two most splendid illustrations for exhibition to a class, are the

combustion of a piece of watch spring, and the exposing a quantity of quicklime in a tobacco pipe mouth, to the oxygen and hydrogen. The large sphere of brilliant sparks evolved from the watch spring, and the intense white light given out by the lime, so splendid that the eye can scarcely bear it, are peculiarly fine.

Water is a transparent and colourless liquid, destitute of smell, and nearly without taste. It freezes at 32° and boils at 212°. Its density is greatest at the temperature of 39°·38, as determined by Halstroem.

According to the determination of Captain Kater, and the other scientific commissioners appointed by the British government, to contrive the best means for fixing an invariable standard of weights and measures, a cubic inch of distilled water, at the temperature of 62°, and when the barometer stands at 30 inches, weighed in air with brass weights, weighs 252·458 grains, and in vacuo, 252·722 grains. Hence at the temperature of 60°, the weight of a cubic inch of water, weighed in air by brass weights, is almost exactly 252·5 grains. *Height of a cubic inch of water.*

Water being the substance most easily procured in every part of the earth in a state of purity, it has been chosen by universal consent, to represent the unit of the specific gravity of all solid and liquid bodies. When we say that the specific gravity of a body is 2, we mean that it weighs twice as much as the same volume of water would do. Now a cubic foot of water, at the temperature of 60, and when the barometer stands at 30 inches, weighs 998·217 avoirdupois ounces, which is only 1·783 ounces less than 1000. Hence if we know the specific gravity of a body, we have very nearly the weight of a cubic foot of it in avoirdupois ounces.

From the experiments of Biot and Arago, we learn that 100 cubic inches of air, at the temperature of 60°, and when the barometer stands at 30 inches, weigh 31·1446 grains. Hence it follows, that water, at that temperature and pressure, is 810·734 times heavier than air.

When water shoots into ice, it forms, in the first place, a prism not very regular in its shape, but very long. From this primary prism other smaller ones shoot out on both sides, and always at angles of 60° and 120. Hail is always crystallized in the form of two six sided pyramids, applied base to base. The faces of the two pyramids meet at angles of about 80°, and one of the pyramids is always truncated.* Dr. Clarke *Crystals of water.*

* See Smithson; Annals of Philosophy (2d series), v. 340.

observed regular crystals of ice at Cambridge, on the 3d January, 1821.   They were rhomboids, the faces of which were inclined to each other, at angles of 120° and 60°.*   Bernardi has endeavoured to deduce from considerations connected with crystallography, that the primary form of ice must be a rhomboid very nearly agreeing with that of calareous spar.†

Water a neutral body.   Water, if we are to judge from the combinations into which it enters, is a neutral substance.   It shows little tendency to combine with simple bodies, whether supporters, or acid or alkaline bases.   But it combines, and apparently with equal readiness, both with acids and bases ; though without disguising their peculiar properties, or neutralizing their energies. It would be improper to consider the combinations which water forms with the alkaline bases, (though it combines with them in definite proportions) as entitling it to be called an acid.   On this account, the term *hydrate*, applied to these combinations by Proust, and now generally employed by chemists, is somewhat objectionable.   Far less should we view it as an alkali when it enters into definite combinations with acids.   It enters as a constituent into many salts, and its presence or absence, and when present, its quantity, produces considerable differences in the specific gravity, the hardness and the shape of the salts. Of this we shall see many examples, when I come to give an account of the *salts.*

It is not easy to form an accurate idea of the way that water unites with other bodies.   The electric theory of combination will scarcely apply to it, or, at least, we cannot determine except from analogy, whether it be positive or negative with respect to those bodies with which it unites.   For if we attempt to decompose such compounds, the water is always in the first place reduced to its elements.

Deutoxide of hydrogen.   Hydrogen is capable of uniting with an additional dose of oxygen, and of forming a new liquid compound, which may be distinguished by the name of *deutoxide of hydrogen.*   For this important discovery we are indebted to M. Thenard. ..His method of proceeding was to dissolve peroxide of barium,‡ in diluted muriatic acid, and then to precipitate the barytes by means of sulphuric acid.   This process is repeated a number of times, and then the muriatic acid is removed by treating the

* Edin. Phil. Journ. vii. 189.
† Schweigger Jahrbuch, ii. 1.
‡ A substance which will be described in a subsequent part of this work.

liquid with sulphate of silver. The sulphuric acid itself is now thrown down by means of barytes or peroxide of barium. Nothing remains but a mixture of water and deutoxide of hydrogen. This mixture is put under the exhausted receiver of an air-pump, along with sulphuric acid, the water gradually evaporates and leaves the deutoxide of hydrogen in a state of purity. Its properties are as follows: •

. Its specific gravity is 1·453. Hence, when poured into Properties. water, we see it fall to the bottom of that liquid like a sort of syrup, though it is very soluble in it. It attacks the epidermis almost instantly, and produces a prickling pain, the duration of which varies according to the quantity of liquid applied to the skin. If this quantity be too great, or if the liquid be renewed, the skin itself is attacked and destroyed. When applied to the tongue it whitens it likewise, thickens the saliva, and produces on the organs of taste a sensation difficult to express; but which approaches to that of tartar emetic. •

Unfortunately this extraordinary compound cannot be pre- Composition. served. If left to itself, whether in the dark, or exposed to the light, it undergoes spontaneous decomposition, oxygen gas being given out. It might, perhaps, be preserved if it were surrounded with ice. But this method, at least in this country, would scarcely be practicable. When heated to the temperature of about 80°, it is decomposed with a violent explosion, oxygen gas being evolved in great abundance. This experiment cannot be made with safety without diluting the deutoxide with a good deal of water. When thus diluted, the oxygen gas evolved may be collected over mercury. M. Thenard found that one volume of deutoxide, thus treated, gave out 475 volumes of oxygen gas. From this he concluded, that it contains just twice as much oxygen, combined with hydrogen, as water does. It is therefore composed of

$$\text{Hydrogen} \quad . \quad . \quad 1$$
$$\text{Oxygen} \quad . \quad . \quad 16$$

Hence if water be a compound of one atom oxygen and 1 atom hydrogen, the deutoxide must be a compound of two atoms oxygen and one atom hydrogen; or of

$$1 \text{ atom hydrogen} = 0·125$$
$$2 \text{ atoms oxygen} = 2·000$$

$$2·125$$

so that an atom of deutoxide of hydrogen weighs 2·125.

It has been exposed to a cold of — 22° without congealing.

This substance exhibits a very remarkable set of phenomena, when acted on by other bodies; in consequence of which, if it could be produced at a sufficiently cheap rate, it would constitute one of the most important of all substances in chemical investigations. As it is capable of being resolved into oxygen gas and water, by a temperature not exceeding 80°, it must be obvious, that many substances which have a strong affinity for oxygen, or for water, must be capable of decomposing it. But many bodies are capable of producing this decomposition by simple contact, without entering into combination either with the oxygen or water. For all the facts relative to these decompositions, hitherto determined, we are indebted to M. Thenard. I shall here give as concise an account of them as possible, consistent with clearness.

Action of different substances on.

The substances, in order to act upon deutoxide of hydrogen, should be in the state of a fine powder. When in this state, every drop of deutoxide let fall upon them, produces a detonation with the sudden evolution of heat, and often of light. The best way is to put the substances into a glass tube, and to let fall upon them, by means of a sucker with a capillary mouth, the deutoxide of hydrogen, drop by drop.

Charcoal and selenium are the only simple non-metallic bodies which act upon it. The selenium is acidified. The charcoal expels the oxygen without combining with it.

Silver, platinum, gold, osmium, palladium, rhodium, and iridium, when in the state of fine powder, decompose it with violence, driving off the oxygen without combining with it. I am disposed to ascribe these decompositions, in part at least, to the elevation of temperature, produced by the capillary attraction of the liquid into the pores of the powders. For when they are in the state of filings or lumps, they still act, but very feebly and slowly.

Lead, bismuth, and mercury, exercise an action, slow at first, but gradually increasing in energy. The oxygen is driven off, and the metals are not oxydized.

Cobalt, nickel, cadmium, copper, act very feebly. Iron, tin, tellurium, antimony, seem to have no action whatever.

Arsenic, molybdenum, tungsten, chromium, as well as potassium and sodium, are oxydized; but a considerable proportion of the oxygen is expelled. Arsenic, molybdenum, potassium, and sodium, act with great energy, light being disengaged. Manganese and zinc are likewise oxydized; but the action of the last of these metals is very feeble.

The metallic sulphurets exhibit phenomena easily explicable. Those of the alkaline bases are converted into sulphates; those of the acidifiable bases are converted into acids, while the sulphur is disengaged.

The action of the metallic oxides is very various. Barytes, strontian, lime, oxide of zinc, the two oxides of copper, oxide of nickel, protoxides of iron, manganese, tin, cobalt, arsenic, &c. doubtless absorb oxygen, and are converted into peroxides.

Most of the calcined oxides expel the surplus oxygen from the deutoxide.

Massicot, teroxide of manganese, peroxide of cobalt, and hydrous peroxide of iron, exercise a more violent action, but are not themselves altered.

The oxides of silver, gold, &c. act with great violence, and not only decompose the deutoxide, but are themselves reduced to the metallic state.

Finally, it may be mentioned that the addition of any acid to the deutoxide of hydrogen, renders it more permanent, and has a tendency to prevent the disengagement of oxygen from it.[*]

2. The compound of hydrogen and chlorine is known by Hydrogen unites to chlo- the names of *muriatic acid* or *hydro-chloric acid.* It has been rine. long known, and is one of the most powerful and useful of all the acids in a chemical laboratory.

If equal volumes of chlorine and hydrogen be put into a glass tube and exposed to the direct rays of the sun, an explosion takes place. This curious fact was first observed by Gay-Lussac and Thenard.[†] When two equal glass vessels, ground so as to fit each other and filled, the one with dry chlorine and the other with hydrogen, are placed in contact and exposed to the light of day, but not to sunshine, the yellow colour gradually disappears and the mixture becomes colourless. If it be now examined it will be found converted Forming mu-riatic acid. into pure muriatic acid gas, equal in bulk to the volume of the two gases before combination.[‡] Hence it follows that this gas is a compound of chlorine and hydrogen. The experiments which led to this conclusion were first made by Gay-Lussac and Thenard. But the consequence was first drawn

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[*] See Annals of Philosophy (2d series), iii. 41.

[†] Recherches Physico-Chimiques, ii. 129. The discovery was likewise made by Dalton, who communicated it to me by letter before the publication above quoted appeared.

[‡] Ibid. p. 128.

by Sir Humphry Davy, who thus revived the original opinion of Scheele, the discoverer of chlorine gas.

Properties.   *Muriatic acid,* called *hydrochloric acid* by Gay-Lussac, is a gaseous body, invisible and elastic like common air, and having a peculiar smell and a very sour taste. Water absorbs it with great avidity, so that it can be preserved only over mercury. No combustible body will burn in it: and it destroys life instantly when an attempt is made to breathe it. Indeed it cannot be drawn into the lungs; the glottis being spasmodically shut whenever it comes in contact with this gas.

Its specific gravity is the mean of that of chlorine and hydrogen, or 1·2847.*

As muriatic acid gas consists of a combination of equal volumes of hydrogen gas and chlorine gas, it is obvious that the specific gravity of those gases exhibits the weight of each which enters into the composition of the acid. It is, therefore, composed of

Composition.   Hydrogen 0·0694 or   1 or 0·125
               Chlorine   2·5000   36   4·5

But we have seen already, that an atom of hydrogen weighs 0·125, and an atom of chlorine 4·5. Muriatic acid, therefore, is a compound of one atom of each constituent, and its atomic weight is 4·625.

Davy ascertained that a mixture of chlorine and hydrogen gases burns at a much lower temperature, and produces a greater degree of heat during the combustion, than oxygen and hydrogen gases. These last gases ceased to explode when rarefied 18 times. But the mixture of chlorine and hydrogen is still combustible when rarefied 24 times.

When this mixture is fired by electricity, the flame is large and white.

Muriatic acid is so important a substance, that its properties deserve to be detailed at greater length than would suit so early a part of this work. I shall, therefore, delay the account of it till I have finished the history of the simple substances.

So far as we know at present, chlorine and hydrogen combine only in one proportion.

Hydrogen unites to bromine.   3. The combination of hydrogen with bromine, is called

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* A set of experiments made in my laboratory gave the specific gravity of muriatic acid gas 1·2843, which almost coincides with the number in the text.

hydrobromic acid.   We are indebted to M. Balard, for all the knowledge of this compound which we at present possess.

It may be obtained by mixing with sulphuric acid, the cubic crystals, produced in M. Balard's process for obtaining bromine, and formerly mentioned,* and heating the mixture in a small retort, the beak of which is plunged under mercury, A gas comes over, which is hydrobromic acid. But when obtained in this manner, it is not quite pure, being usually mixed with some sulphurous acid, and frequently with muriatic acid.   The best method of obtaining it is to moisten the compound of bromine and phosphorus (*bromide of phosphorus*) with water in a small retort, and to expose it to the heat of a lamp, while the beak of the retort is plunged under mercury.   Hydrobromic acid gas comes over in abundance.†

Hydrobromic acid is a colourless gas, having an acid taste, and smoking when mixed with atmospherical air.   It is not altered when left standing over mercury; but water absorbs it in abundance, and when saturated with it, constitutes liquid hydrobromic acid.   When tin is heated in this gas it combines with the bromine of the acid, and leaves the hydrogen.   Potassium produces the same decomposition at the common temperature of the atmosphere.   When 100 volumes of the gas are thus decomposed, the residual hydrogen gas amounts to precisely 50 volumes.   From this it follows, that hydrobromic acid, like muriatic acid, is a compound of equal volumes of bromine vapour and hydrogen gas united together, without any alteration in bulk.

When chlorine gas is mixed with hydrobromic acid, the bromine is immediately precipitated in drops, and muriatic acid formed, equal in volume to that of the original gas. - But it is not decomposed by oxygen nor iodine even at a red heat. Neither is bromine capable of decomposing water when the mixed vapours of the two liquids are passed through an ignited porcelain tube.

There can be no doubt from the analogy of chlorine and iodine, that a volume of bromine vapour represents an atom. Hydrobromic acid then must be a compound of 1 atom bromine and 1 atom hydrogen.   Hence its atomic weight must be 10·125.   I have shown elsewhere that its specific gravity will be obtained by multiplying its atomic weight by 0·2777, or $\frac{1}{4}$th

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* See page 71 of this volume.
† Ann. de Chim. et de Phys. xxxii. 347.

the specific gravity of oxygen gas.*   Hence the specific gravity of hydrobromic acid gas ought to be 2·8125.

Hydriodic acid.   4. Hydrogen and iodine, when united together, constitute a gaseous substance, distinguished by the name of *hydriodic acid*. It seems to have been first discovered by M. Clement; but its nature and properties were first investigated by Davy† and Gay-Lussac.‡

It may be obtained by mixing together four parts of iodine and one part of phosphorus, moistening the compound with water and heating it in a small retort. A gas comes over which must be received over mercury. This gas is hydriodic acid.

Properties.   It is colourless and elastic like common air. It has a smell similar to that of muriatic acid, and a very acid taste.

When this acid is left in contact with mercury it is decomposed, the mercury combines with the iodine and forms an iodide, while a quantity of hydrogen gas is disengaged exactly equal to half the bulk of the hydriodic acid gas. It is decomposed likewise by chlorine, muriatic acid is formed, and the iodine is deposited. These experiments leave no doubt about its composition. It consists of one volume of vapour of iodine united to one volume of hydrogen gas, without any change of bulk. Hence it is composed by weight of

Composition.
> ' Iodine   . .   8·75   . or . 15·75
>   Hydrogen   . 0·0694 .   .   0·125

We see from this that it is composed of an atom of iodine united to an atom of hydrogen. And its atomic weight must be 15·875.

Its specific gravity should be obtained by multiplying its atomic weight by 0·2777. This gives 4.40972 for the specific gravity of this gas, a number not differing so much as one per cent. from 4·443, the specific gravity of this gas determined by Gay-Lussac by actual experiment.§

Water absorbs this acid with avidity. When exposed to a heat below 262°, the water is driven off and the acid becomes concentrated. In this way its specific gravity may be increased to 1·7. At 262° the acid boils and may be distilled over. It readily dissolves iodine, and becomes of a darker colour. It becomes dark coloured also by exposure to the air, being partly decomposed.

* See First Principles of Chemistry, i. 246.
† Phil. Trans. 1814, p. 74.   ‡ Ann. de Chim. xci. 9.
§ Ann. de Chim. xci. 16.

5. It is at present generally admitted by chemists, that *fluoric acid* is a compound of *fluorine* and *hydrogen ;* though hitherto it has been impossible to decompose it, or to obtain the fluorine in a separate state.

Scheele first made this acid known, but he did not obtain it in a state of purity. For the first process, for procuring this acid pure, we are indebted to Mr. Knight.* But it is to Gay-Lussac and Thenard that we are indebted for the first examination of its properties.†

It is obtained by putting a mixture of pure fluor spar and sulphuric acid into a retort of lead or silver, and distilling into a leaden or silver receiver. It is a colourless liquid, of the specific gravity 1·0609. It smokes strongly when exposed to the air. It acts with prodigious energy upon the skin. The smallest speck occasioning sores. If we conclude from the analogy of the other hydracids that fluoric acid is a compound of

$$
\begin{array}{llr}
\text{1 atom fluorine} & . \ . & 2{\cdot}25 \\
\text{1 atom hydrogen} & . \ . & 0{\cdot}125 \\
\hline
& & 2{\cdot}375
\end{array}
$$

its atomic weight will be 2·375.

I reserve a more detailed account of this important acid, to a subsequent part of this work.

Such are the compounds which hydrogen forms with the *supporters*, so far as the subject has been investigated. No attempts have been made to unite it with a greater quantity of chlorine, bromine, iodine, or fluorine, than exist in the respective hydracids, which have been just noticed. There is little doubt from the analogy of the deutoxide of hydrogen, that they might all be made to unite with it in a greater proportion.

The order in which these compounds of hydrogen and supporters are decomposed by the supporters, may be represented as follows.

Hydrogen	Oxygen
Fluorine	Bromine
Chlorine	Iodine.

That is to say, that hydriodic acid is decomposed by all the supporters except iodine ; hydrobromic acid is decomposed by chlorine and oxygen, but not by iodine: water is decomposed

* Phil. Mag. (1st series) xvii. 357.
† Recherches Physico-Chimique, ii. 2.

by chlorine, at least when assisted by light; but not by bromine nor iodine. As to fluoric acid it is not decomposed by any of the supporters, even when assisted by heat. Notwithstanding this order of decomposition, it is pretty obvious, that oxygen (at least at common temperatures) is more negative than chlorine. I endeavoured in a preceding part of this work to account for the apparent anomaly in the action of chlorine on water, and need not therefore resume the subject here.*

SECTION II.—OF AZOTE.

Discovery.   This gas, which constitutes so great a portion of common air, was first recognised as a peculiar substance in 1772 by Dr. Rutherford, afterwards Professor of Botany in the University of Edinburgh.† Scheele, in his treatise *On Air and Fire*, published in 1777, showed analytically that air is a mixture of oxygen and azotic gases.‡ But Lavoisier informs us that he recognised the existence of azote in air as early as 1773.‖ And, indeed, in his Essays, published in 1773, there is a chapter on the properties of air in which phosphorus has been burnt. But how he could recognise the constitution of air before the discovery of oxygen, it is not easy to understand.

How obtained.   Azotic gas being one of the constituents of common air, is easily procured from it by different processes. 1. If we leave a stick of phosphorus in a jar of air inverted over water or mercury till it ceases to smoke, (which in summer will be the case in 24 hours,) the gas remaining in the jar, after having been washed with water is azotic gas. 2. If we mix 100 volumes of common air and 42 volumes of hydrogen gas, and pass an electrical spark through the mixture, or put into it a platinum clay ball, combustion takes place and the residual gas is azote very nearly pure. 3. If we mix in a wide jar

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* See Introduction, p. 40, &c.

† See his thesis De Aere Mephitico, published in 1772.—" Sed aer salubris et purus respiratione animali non modo ex parte fit mephiticus, sed et *aliam indolis suæ mutationem inde patitur.* Postquam enim omnis aer mephiticus (*carbonic acid gas*) ex eo, ope lixivii caustici secretus et abductus fuerit, *qui tamen restat* nullo modo salubrior inde evadit; nam quamvis nullam ex aqua calcis præcipitationem faciat haud minus quam antea *et flammam et vitam extinguit,*" page 17. When Hauxbee passed air through red-hot metallic tubes, he must have obtained this gas; but at that time the difference between gases was ascribed to fumes held in solution. See Phil. Trans. Abr. v. 613.

‡ English Translation, p. 7.

‖ See his remarks on Scheele's works, Mem. Par. 1781, p. 397.

standing inverted over water, 100 cubic inches of common air with 80 cubic inches of deutoxide of azote,* a great diminution of volume takes place, red fumes appear which are absorbed by the water, and about 80 cubic inches of a gas remains which is azote, nearly in a state of purity. 4. If a small tubulated retort be filled with chloride of lime or bleaching powder, brought into the consistency of cream by water, and pieces of sal ammoniac be put into the retort through the tubular, a pretty strong effervescence takes place, and azotic gas is disengaged abundantly. It may be collected over water by plunging the beak of the retort under the mouth of an inverted jar standing in the water trough. When thus procured it is quite pure; provided sufficient care be taken to exclude all common air from the inside of the retort containing the mixtures of choride of lime and sal ammoniac.

1. Azotic gas possesses the mechanical properties of common air. Like that fluid it is destitute of colour, taste, and smell. *Properties.*

2. Its specific gravity was determined by Biot and Arago at 0·969.† I took the specific gravity of a portion of this gas, prepared with much care, to ensure its purity, and obtained 0·9730, reckoning the specific gravity of common air to be unity. It will appear afterwards from the facts about to be stated in this section, that the atom of azote weighs 1·75. Now, $1·75 \times 0·5555 = 0·9722$; which must therefore be the true specific gravity of this gas. If common air be a mixture of 80 volumes of azotic gas and 20 of oxygen; and if the specific gravity of oxygen gas be 1·1111, then that of azotic gas must be 0·9722. For $\dfrac{20 \times 1·1111 + 80\,x}{100} = 1$ and $x = 0·9722$. From all these circumstances there cannot be the least doubt that the true specific gravity of this gas is 0·9722.

3. It refracts light rather more powerfully than air. If we reckon the refracting power of air 1, then that of azotic gas will be 1·020, as determined by Dulong.‡

4. It cannot be breathed by animals without suffocation. If obliged to breathe it they die very soon, precisely as they would do if plunged under water. Hence the term *azote* given to this substance by the French chemists, which signifies " destructive of life."‖

* A gas to be described in a subsequent part of this section.
† Mem. de l'Instit. 1806, p. 320.
‡ Ann. de Chim. et de Phys. xxxi. 166.   ‖ From α and $\zeta\omega\eta$.

No combustible will burn in it. Hence the reason that a candle confined in a given portion of air, goes out as soon as the oxygen surrounding it is consumed.

5. This gas is not sensibly absorbed by water; nor indeed are we acquainted with any liquid which has the property of condensing it. Dr. Henry ascertained, that when water is previously deprived of all the air which it contains, 100 inches of it are capable of absorbing only 1·47 inches of azotic gas at the temperature of 60°.* According to Mr. Dalton, the quantity of azote which 100 cubic inches of water take up is $2\frac{1}{2}$ cubic inches.† But he drew this conclusion from theoretical considerations, the justice of which is rather problematical.

6. No degree of pressure and cold hitherto applied has been able to condense this gas into a liquid state. It is certain that a pressure of 1000 atmospheres is not sufficient for this purpose.

II. Azote has doubtless the property of uniting with all the supporters of combustion; though chemists have not yet been able to investigate all of these combinations in a satisfactory manner. The following facts, however, have been ascertained.

Compounds
with oxygen.
1. With oxygen it unites in no fewer than five different proportions, constituting the five following compounds.

1. Protoxide of azote,
2. Deutoxide of azote,
3. Hyponitrous acid,
4. Nitrous acid,
5. Nitric acid.

The last of these compounds exists in *saltpetre*, which is a salt composed of nitric acid and potash. This salt forms spontaneously in the soil of different countries. The presence of animal matters and of lime have been found to promote its formation. It is obtained in different parts of the world by lixiviating the soil and evaporating the lixivium to dryness, or till crystals are deposited. These crystals are afterwards purified by a second crystallization.

Saltpetre.
When 12·75 parts of pure saltpetre, previously rendered as dry as possible by exposure for some hours to a heat above 212°, are mixed in a retort with 6·125 parts of sulphuric acid of the specific gravity 1·837; and heat applied by putting the belly of the retort into a sand bath placed on a furnace, a red

* Phil. Trans. 1803, p. 274.
† Annals of Philosophy, vii. 219. Saussure makes the quantity 4·1 cubic inches (Ann. of Philos. vi. 340), but he seems to have overrated it.

fuming liquid passes into the receiver, which is nitric acid. The retort should have an adopter luted to it, and the receiver should be kept cool, either by being surrounded by a mixture of snow and salt, or at least by being kept always wet with a current of cold water constantly renewed. When the proportions of saltpetre and sulphuric acid mentioned above are employed, and the distillation properly conducted, the nitric acid obtained is as strong as possible; though from the high temperature requisite to distil it over, a portion of it is always decomposed and destroyed during the process. The consequence of this decomposition, is the evolution of oxygen gas (mixed with azotic gas), towards the end of the process, in considerable quantity.

Nitric acid thus obtained is a yellowish red liquid, which Nitric acid. has a peculiar smell, and smokes when placed in contact with atmospheric air. When heated a gaseous matter is driven off, and it becomes colourless like water. I have never myself by this process obtained nitric acid of a higher specific gravity than 1·534. But it is said to have been obtained as high as 1·55. Its taste is intensely sour. When applied to any part of the body it acts as an escharotic and speedily produces a sore by destroying the texture of the part. It is one of the most powerful and most useful of all the acids.

Nitric acid combines readily with potash and converts it into nitrate of potash or saltpetre; the salt from which it was originally obtained. Saltpetre is a white salt, which crystallizes in six sided prisms, has a cooling and saline taste, and produces no alteration in vegetable blue colours. It is therefore neutral, and composed of an integrant particle of nitric acid united to an integrant particle of potash. Now, I find that if we take a quantity of carbonate of potash, containing exactly 6 parts of potash, and saturating it with nitric acid, evaporate the whole to dryness in a platinum crucible, the nitrate of potash formed will weigh precisely 12·75 parts. From this it follows that saltpetre is composed of

| Potash | . | . | . | 6 |
| Nitric acid | | . | . | 6·75 |

| | 12·75 |

So that, if the atom of potash be 6, that of nitric acid will be 6·75.

When nitrate of potash is exposed to a red heat, the nitric acid is decomposed and converted into oxygen and azotic

gases; showing that this acid is a compound of oxygen and azote. The proportions of these two constituents will appear afterwards. The true component parts of nitric acid were discovered by Mr. Cavendish, and communicated by him to the Royal Society on the 2d of June, 1785. He formed nitric acid by causing a mixture of oxygen and azotic gases to unite by passing electric sparks through it, placed in a glass tube standing over mercury, and containing an aqueous solution of potash, which was found to facilitate the formation of the acid. The result of his experiment was, that nitric acid is a compound of 1 volume azotic gas and 2 volumes oxygen gas. We shall see immediately that the true composition is 1 volume of azotic gas and 2·5 volumes of oxygen gas.

1. Protoxide of azote.

(1.) If we saturate nitric acid with ammonia or carbonate of ammonia, and evaporate the solution, we obtain a fibrous white and deliquescing salt called *nitrate of ammonia*. If we put this salt into a small retort, the beak of which is plunged into the water or mercurial trough, and raise the temperature of the salt by means of a spirit lamp to about the temperature of 400°, it melts and froths strongly, giving out a colourless gas, which should be received into glass bottles furnished with air-tight stoppers.

This gas was originally discovered by Dr. Priestley about the year 1776, and called by him *dephlogisticated nitrous gas.** The associated Dutch chemists examined it in 1793, and showed it to be a compound of azote and oxygen.† But for a full investigation of its properties we are indebted to Sir H. Davy, who published an excellent set of experiments on it in the year 1800.‡ He gave it the name of *nitrous oxide*.

Properties.

This gas is colourless and invisible like common air. It has a sweetish taste. Its specific gravity, determined with as much care as I could bestow upon it, turned out in three successive trials to be 1·5269. But it was not in all probability quite free from all admixture of common air. Gay-Lussac first showed by decisive evidence that it is a compound of 1 volume of azotic gas and half a volume of oxygen gas condensed into one volume. Hence we must obtain the true specific gravity of this gas by adding together the specific gravity of azotic gas and half the specific gravity of oxygen gas.

* Priestley on Air, ii. 54.   † Jour. de Phys. xlii. 323.
‡ *Researches, chiefly concerning nitrous oxide.*

Sp. gr. of azotic gas . . 0·9722

½ sp. gr. of oxygen gas . . 0·5555

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1·5277 = true speci-

fic gravity of protoxide of azote.

Water absorbs about ¾ths of its volume of this gas. According to the experiments of Saussure, 100 volumes of water absorb 76 volumes of protoxide of azote; and 100 volumes of alcohol of the specific gravity 0·84 absorb 153 volumes.*

According to the experiments of Dulong, if we reckon the refracting power of common air 1, that of protoxide of azote will be 1·710.†

It is capable of supporting combustion, and bodies burn in it almost as brilliantly as they do in oxygen gas. But there are two remarkable differences between the combustion of bodies in these two gases. No substance burns in protoxide of azote till it has been heated to whiteness. You may touch phosphorus with a red hot wire, you may even sublime it in this gas without any tendency to combustion. But the moment you touch it with a white hot wire it catches fire and burns with great brilliancy. If you set fire to sulphur and plunge it into this gas, it is immediately extinguished. But if you heat a wire to whiteness and touch the sulphur with it, the sulphur immediately takes fire, and burns with a fine rose-coloured flame. 2. The second circumstance which distinguishes the combustion of bodies in this gas, is the shortness of the time that they continue to burn. If you set fire to a piece of cotton attached to an iron wire, and plunge it into this gas, the iron wire catches fire, and begins to burn with as much splendour as it would do in oxygen gas. But this combustion does not continue, for in an instant or two the wire is extinguished.

Dr. Priestley and the Dutch chemists had concluded that this gas cannot be breathed; but Davy ascertained that it could be breathed for several minutes without any bad effects. The feelings produced by breathing it bear a strong resemblance to intoxication; but they are not followed by that languor and debility which is a constant attendant of intoxication. It cannot be breathed longer than about four minutes, without the loss of voluntary motion altogether. When animals are confined in it, they give no signs of uneasiness for

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* Annals of Philosophy, vi. 340.

† Ann. de Chim. et de Phys. xxxi. 166.

some moments; but they soon become restless, and if not removed in a very few minutes, die altogether. Hence we see, that though this gas be respirable, it is much less so than common air or oxygen gas.*

This gas is not altered by exposure to light nor to any heat below ignition; but when made to pass through a red hot porcelain tube, or when electric sparks are passed through it, decomposition takes place and nitric acid is formed.†

It is one of the gases which Mr. Faraday succeeded in reducing to a liquid state by pressure; as might have been anticipated from its great absorbability by water. The pressure requisite, was that of 50 atmospheres, at the temperature of 45°. Liquid protoxide of azote is transparent and colourless, and so volatile, that the warmth of the hand caused it to disappear in vapour. It had no tendency to become solid, though cooled down to — 10°.‡

Composition. When protoxide of azote is mixed with hydrogen gas, and an electric spark passed through the mixture, detonation takes place, as was first observed by Dr. Priestley.§ The Dutch chemists ascertained, that when the two gases were mixed in the requisite proportions, they were converted completely into water and azote.‖ The most accurate experiments were those of Davy. He found the best proportions to be equal volumes of hydrogen and protoxide of azote. When 46 volumes of each gas were mixed together, the residue of azote gas, after combustion, was 49 volumes.¶ I found that when 100 volumes of pure hydrogen gas and 100 volumes of deutoxide of azote, both as dry as possible, are detonated over mercury, the azotic gas remaining after combustion, (supposing the barometer at 30 inches, and the thermometer at 60°) amounts to 101·77 volumes. But a quantity of water has been deposited on the sides of the eudiometer. Consequently, the azotic gas is saturated with moisture at 60°. When rendered perfectly dry, its volume will be reduced to 100.** It is evident from this experiment, as well as from those of Gay-Lussac, Henry, &c. that protoxide of azote contains exactly its own volume

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* Davy's Researches, p. 94.
† Priestley on Air, ii. 91. and Davy's Researches, p. 279.
‡ Phil. Trans. 1823, p. 195.   § On Air, ii. 83.
‖ Jour. de Phys. xliii. 331.   ¶ Researches, p. 288.
** Let the volume of dry gas be x, let $p = 30$ inches and $f = 0.524$. We have $\dfrac{p \, x}{p-f} = 101.77$. Hence $x = 100$. See First Principles of Chemistry, i. 115.

of azotic gas. The hydrogen being converted into water, it is obvious that the other constituent must be oxygen. And as hydrogen requires half its volume of oxygen to convert it into water, it is clear that a volume of protoxide of azote contains likewise half a volume of oxygen gas. Thus the constituents of this gas are obviously 1 volume of azotic gas, and ½ a volume of oxygen gas united together and condensed into 1 volume. The constituents of the gas by weight are obviously determined by the specific gravity of the two gaseous constituents: viz.

Azote . . 0·9722 or 1·75
Oxygen . . 0·5555 or 1

It is obvious from this that the atomic weight of azote is either 1·75, or at least a multiple or submultiple of that number.

Charcoal may be burnt in protoxide of azote by means of a burning-glass. It burns with considerable brilliancy. Davy found that when charcoal plunged under mercury, in a state of ignition, was introduced into 3 cubic inches of protoxide of azote, and kindled by a burning-glass, it burned for about ten minutes. The volume of residual gas was 4·2 cubic inches.* Caustic potash absorbed 1·15 cubic inches of this residue, which, consequently, was carbonic acid. The remaining 3·05 cubic inches were azotic gas.† This experiment shows also that protoxide of azote contains its own volume of azotic gas. The carbonic acid evolved should have been 1·5 cubic inches. But it is easy to account for the deficiency, from the well known property which charcoal has of absorbing carbonic acid.

Phosphorus, phosphuretted hydrogen, sulphur, and sulphuretted hydrogen, were also burnt in protoxide of azote, by Sir H. Davy, but the results were not sufficiently precise to determine the constituents with accuracy.

Protoxide of azote is probably a neutral substance; at least we have no evidence that it possesses either acid or alkaline properties. For it will not combine either with acids or with bases. Davy, indeed, found that when it is presented to an alkali in its nascent state, a combination may be formed. He mixed together sulphite of potash and caustic potash, and placed the mixture in contact with deutoxide of azote.‡ The

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* It is obvious that a little of the carbonic acid gas, generated, would be absorbed by the charcoal.

† Researches, p. 311.

‡ This gas will be described in a subsequent part of this section.

sulphite absorbed oxygen from the gas, and converted it into protoxide, and this protoxide being in contact with potash at its formation, combined with it, and formed a peculiar salt, to which Davy gave the name of *nitroxi of potash*. This salt had no recognisable crystalline form. Its taste was caustic and pungent. It rendered vegetable blues green, indicating that the potash had not been completely saturated with protoxide of azote. With charcoal, when heated, it burnt with slight scintillations. The acids placed in contact with it extricated protoxide of azote. Heat produced the same evolution of gas. Davy succeeded in combining protoxide of azote with soda; but not with ammonia, or with lime, barytes, or strontian, or the earthy bodies.* These experiments would lead to the conclusion that protoxide of azote possesses *acid* properties. But notwithstanding the evolution of protoxide of azote from this salt by heat, I am strongly inclined to suspect that it was not this gas, but hyponitrous acid, newly formed by the process, which united to the alkali. The subject is well entitled to farther investigation, and promises, if properly prosecuted, to throw additional light on the nature of some of the combinations of oxygen and azote.

2. Deutoxide of azote.

(2.) When nitric acid diluted with water is put into a small retort, or flask, with small pieces of copper, it acts with considerable energy on that metal. Heat is evolved, the liquid assumes a blue colour, the copper is oxydized at the expense of the acid, an effervescence takes place, and a gas is extricated in considerable quantity. This gas is *deutoxide of azote*.†

It was accidentally discovered by Dr. Hales; but its nature and properties were first investigated by Dr. Priestley, who gave it the name of *nitrous air*, or *nitrous gas*, by which it was long known to chemists. It was afterwards called *nitric oxide*. And after its composition was accurately determined, I substituted the term *deutoxide of azote* as a more appropriate denomination. And this name is now pretty generally adopted. The first accurate experiments to determine its constitution, were those of Sir H. Davy.‡ Gay-Lussac first succeeded in giving a correct view of the proportions of its constituents.§

* Researches, p. 254.

† When we wish to procure deutoxide of azote quite pure, it is better to employ mercury than copper. However, we may succeed almost equally well with copper, provided we use acid sufficiently dilute, and take care to prevent any augmentation of temperature during the solution of the copper.

‡ Researches, p. 122.   § Mem. d'Arcueil, ii. 207.

To obtain the deutoxide of azote pure, the nitric acid should not exceed the specific gravity of 1·25. And care should be taken not to begin to collect it till after the gaseous matter in the retort, or flask, containing the acid and copper, has become perfectly transparent and colourless, like common air. Even with every precaution it is difficult to procure it perfectly free from all admixture of azotic gas. Its properties are as follows.

1. It is colourless and invisible like common air, of which Properties. it possesses the mechanical properties. Whether it has any taste or smell, is not easily determined, because whenever it is mixed with air, *nitrous acid* is formed, which communicates its taste and its peculiar odour to the gas. For the same reason we cannot determine whether or not it is capable of being breathed. Sir H. Davy, in a fit of enthusiasm, made an attempt to breathe it. He made several inspirations of protoxide of azote, to free the lungs as completely as possible from common air. He then attempted to inspire deutoxide of azote. It felt in the mouth astringent and highly disagreeable. It occasioned a sense of burning in the throat, and produced a spasm of the epiglottis, so painful, as to prevent the possibility of introducing the gas into the lungs.* It is obvious that the common air of the lungs had not been completely replaced by the protoxide of azote. Hence, a little nitrous acid was formed in the mouth, which, fortunately, prevented the gas from being drawn into the lungs. Had Davy succeeded in filling his lungs with this gas, the result would certainly have proved fatal. Because, as soon as he began to breathe common air, nitrous acid would have been formed in the lungs, which must have destroyed their texture.

2. The mean of three trials, to determine the weight of this gas, gave me for its specific gravity 1·04096.† But Gay-Lussac has demonstrated that it is composed of equal volumes of oxygen and azotic gases united together, without any alteration of density.‡ Hence the true specific gravity must be the mean of that of oxygen and hydrogen gases, or 1·0416. My result, which is about $\frac{1}{1488}$th part less than this, was probably owing to the gas which I weighed being contaminated with a little azotic gas, derived from the water over which it stood.

3. If we reckon the refracting power of air 1, then that of

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* Researches, p. 175.　　　　† First Principles, p. 118.
‡ Mem. d'Arcueil, ii. 216.

deutoxide of azote, according to the experiments of Dulong, is 1·03.*

4. This gas, when pure, produces no sensible effect on vegetable blues. Nor does it appear to possess the characters of either an acid or an alkali.

5. This gas is not sensibly absorbed by water. However, when agitated with that liquid freed from air by boiling, 100 volumes of the water, absorb about 5 parts of the gas.† From this small absorbability it is plain, that this gas cannot easily be deprived of its elasticity. Accordingly, it has resisted all attempts hitherto made to condense it into a liquid, by the application of cold and pressure.

6. When this gas is mixed with common air, or oxygen gas, or any gaseous mixture, of which oxygen gas is one of the constituents, red fumes are produced, heat is evolved, and the volume of the gas diminishes. This is owing to the immediate combination of oxygen and deutoxide of azote into an acid, which is absorbed by the water. If the oxygen and deutoxide of azote be both perfectly pure, and mixed in the requisite proportions, they disappear completely, being totally converted into acid, which combines with the water.

This very remarkable property of deutoxide of azote was first observed by Dr. Priestley, and was employed by him to determine the quantity of oxygen in air, or any gaseous mixture. This was done by mixing the air and deutoxide of azote in certain determinate proportions, in a tube over water, and noting the diminution of volume. The greater the diminution, the better the air was considered to be, or the fitter for the processes of respiration and combustion. Hence the graduated Eudiometers. tube, used for this purpose, was called a *eudiometer* (or *measurer of the goodness of air*). Priestley's original eudiometer was rendered more convenient by Fontana, who employed a narrow glass tube, shut at one end, and divided into 100 equal parts. Hence the apparatus was known among chemists by the name of *Fontana's eudiometer*. It was used very freely by chemists and physicians to determine the relative goodness of air in different places, and great diversity was observed in the goodness of the air in different localities. To this was ascribed the healthiness or unhealthiness of particular places. Till at last Mr. Cavendish, by a course of observations continued for

* Ann. de Chim. et de Phys. xxxi. 166.
† Henry; Phil. Trans. 1803, p. 274.

a year, showed that the relative proportions of oxygen and azotic gases are always the same, and that the apparent differences observed, were owing to the oxygen of the air, and the deutoxide of azote uniting in different proportions, according to the mode in which they were mixed.*

Mr. Dalton was the first person who attempted to account for the anomalies which present themselves when we mix deutoxide of azote with oxygen gas or common air. He found that 21 volumes of oxygen gas are capable of uniting with either 36 volumes, or with 72 volumes of deutoxide of azote; with the former proportion when the deutoxide is let up to the oxygen or air in a narrow tube; with the latter proportion, when the mixture is made in a wide vessel.† But in his New System of Chemical Philosophy, he modifies these numbers somewhat, and asserts that 100 volumes of oxygen may be made to combine with 130, 180, and 360 volumes of deutoxide of azote.‡ Gay-Lussac states, that according to his experiments (allowing for inaccuracies), 100 volumes of oxygen gas may be made to combine with 200 or 400 volumes of deutoxide of azote.§ I have made many experiments to determine the proportions in which oxygen and deutoxide of azote combine. The result is, that when we employ a tube of 0·9 inch in diameter, and let up deutoxide of azote to common air already in the tube, and employ no agitation, 100 volumes of oxygen gas combine very nearly with 200 volumes of deutoxide. When we put deutoxide of azote into a globular vessel, and let up common air to it, bubble by bubble, agitating after every additional bubble (as was practised by Mr. Cavendish), then 100 volumes of oxygen gas combine with 400 volumes of deutoxide.‖ As all intermediate proportions between 200 and 400, may combine with 100 of oxygen gas, we need not be surprised at the great variation in experiments made in this way, and at the little confidence which can be put in the analysis of gaseous mixtures, by means of deutoxide of azote. Indeed, so little can this method be depended on, that I have abandoned it altogether, excepting as far as it serves to indicate the presence or absence of oxygen gas, in a gaseous residue under examination.

7. Dr. Priestley made the fortunate observation that this

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* Phil. Trans. 1783, p. 107. † Phil. Mag. xxiii. 351. ‡ Vol. ii. 327.
§ Ann. de Chim. et de Phys. i. 394.
‖ See Annals of Philosophy (second series), i. 321.

gas is absorbed by water, holding in solution protosulphate of iron or *green vitriol*, as it is also called. The solution assumes a dark brown colour, and becomes opaque. When heated, the greater part of the gas is again expelled unaltered. But if it be allowed to remain, the gas is gradually decomposed, and the iron peroxydized. Davy ascertained that a saturated solution of green muriate of iron (or protochloride of iron) absorbs this gas with more rapidity, and in much greater quantity, than protosulphate of iron does. A cubic inch of saturated solution of protosulphate of iron absorbs 12 cubic inches of this gas; while the same quantity of protochloride of iron absorbs 24 cubic inches.[*] The protonitrate of iron likewise absorbs this gas, as is evident from the dark brown colour of iron, dissolved in very dilute nitric acid, screened from the action of the atmosphere. Davy ascertained, that solution of protosulphate of tin absorbs about $\frac{1}{8}$th of its volume of this gas; and that solutions of sulphate of zinc, and of muriate of zinc, absorb about $\frac{1}{10}$th of their volume of it. White prussiate of iron absorbs it abundantly, and acquires a chocolate colour.[†]

8. Dr. Priestley found that when electric sparks are made to pass through this gas, it gradually undergoes decomposition, and is converted into nitrous acid and azotic gas.[‡] Supposing the decomposition complete, and the acid in contact with water, and absorbed by it, we can easily see that the residual azotic gas must be just $\frac{1}{4}$th of the volume of the original deutoxide of azote. Gay-Lussac ascertained, that when strongly heated by being passed through an ignited porcelain tube, it undergoes the same decomposition.[§]

9. Dr. Priestley observed, that Homberg's pyrophorus takes fire of its own accord when introduced into this gas, and that when charcoal in combustion is introduced into it, the combustion continues with considerable splendour. Davy observed, that phosphorus previously kindled when introduced into this gas, burns with great splendour.[||] When mixed with hydrogen gas, it causes it to burn with a green-coloured flame. But these two gases, in what proportion soever mixed, do not detonate by the electric spark; though they are decomposed by spongy platinum at the common temperature.[¶] A mixture

* Researches, p. 179.   † Researches, p. 189.
‡ On Air, ii. 22.   § Ann. de Chim. et de Phys. i. 398.
|| Researches, p. 135.   ¶ Henry's Chemistry, i. 335.

of $1\frac{1}{2}$ volumes of deutoxide of azote, and 1 volume of ammonia, detonate by an electric spark, as was first observed by Dr. Henry.*

From Davy's experiments, it appears that when 16 volumes of this gas are decomposed by charcoal, and the carbonic acid formed removed by caustic potash, there remain 8 volumes of azotic gas,† at least very nearly. Gay-Lussac has shown by very convincing arguments, that this gas is composed of equal volumes of oxygen and azotic gases, united without any alteration of volume. This coincides with the result of Davy's decomposition, and leaves no doubt that the constituents by weight, are

$$
\begin{array}{llr}
\text{Oxygen} & . & . & 1\cdot1111 \text{ or } 2 \\
\text{Azotic} & . & . & 0\cdot9722 \text{ or } 1\cdot75;
\end{array}
$$

so that deutoxide of azote (supposing the weight of azote the same) contains twice as much oxygen as protoxide of azote does.

10. It was observed by Dr. Priestley, that when moistened iron filings are left in contact with deutoxide of azote, the volume of the gas gradually diminishes, ammonia is formed, and the gas is at last converted into protoxide of azote. At the same time the iron is converted into protoxide. Davy showed that the decomposition of the deutoxide, in this case, is owing to the action of the hydrogen set at liberty from the water by the oxydizement of the iron. But the theory of the process is not very clear. It is obvious that water must be formed as well as ammonia, otherwise the change could not take place. 12 volumes of deutoxide of azote thus decomposed, left five volumes of protoxide of azote.‡ Were we to consider these numbers as quite accurate, it would be easy to exhibit the process of decomposition. Three volumes of hydrogen gas evolved from the water, must combine with one volume of azotic gas from the deutoxide, and form 2 volumes of ammonia; while, at the same time, 7 volumes of nascent hydrogen from the same source, must combine with 3·5 volumes of oxygen contained in the deutoxide, and form water. For 12 volumes of deutoxide of azote are composed of 6 azotic + 6 oxygen gas. From which, if we subtract 1 volume of azotic, and 3·5 volumes of oxygen gases, there will remain 5 volumes azotic + 2·5 volumes oxygen gas; which united together, would constitute 5 volumes of protoxide of azote. Zinc may

* Phil. Trans. 1809, p. 445.   † Researches, p. 126.

‡ Davy's Researches, p. 207.

be substituted for iron in this decomposition with the same result.

It was ascertained by Austin and Kirwan,[*] that when dry sulphuretted hydrogen gas is mixed with deutoxide of azote, mutual decomposition takes place; sulphur is deposited, ammonia formed, and if the gases have been mixed in the requisite proportions, there remains at last nothing but a quantity of protoxide of azote. Davy ascertained that in this case no sulphurous nor sulphuric acid was formed, and that 5 cubic inches of deutoxide left a residue of 2·2 cubic inches of protoxide.[†] If these numbers were correct, it would follow that 50 volumes of deutoxide, in order to be completely converted into protoxide, should be mixed with 37 volumes of dry sulphuretted hydrogen gas. This last gas, supposing the sulphur deposited, would leave 37 volumes of hydrogen. Nine of these volumes uniting with three of azotic, would form 6 volumes of ammonia. While the remaining 28 volumes of hydrogen, uniting with 14 of oxygen, would form water.

Fifty volumes of deutoxide of azote, consist of 25 volumes azotic + 25 volumes oxygen gases. From which, if we withdraw 3 volumes azotic, and 14 oxygen, there will remain 22 volumes of azotic, and 11 volumes of oxygen gases, which united together, will constitute 22 volumes of protoxide of azote.

The Dutch chemists ascertained that deutoxide may be converted into protoxide of azote by the action of protomuriate of tin, ammoniacal solution of copper or heated sulphur. Priestley had previously shown that the alkaline sulphurets produce the same effects; and Davy found that the sulphites produce this change with greater rapidity than any other set of substances.[‡] All these bodies seem to act simply by abstracting oxygen. The change of volume has not been accurately determined; but it is obvious, that if nothing else is done than merely abstracting oxygen, the gas must be reduced to half its original volume. For 100 volumes of deutoxide of azote is composed of

<div align="center">

Volumes. Volumes.
50 azotic + 50 oxygen gases.

</div>

If we abstract half the oxygen, there will remain 50 azotic

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[*] Phil. Trans. 1786, p. 133.   [†] Researches, p. 203.
[‡] Researches, p. 199.

+ 25 oxygen, which will constitute 50 volumes of protoxide of azote.

(3.) When deutoxide of azote is put into a wide glass ves- sel suspended inverted over the water trough, and oxygen gas or common air is let up, bubble by bubble, and the gas is well shaken every time that a bubble of oxygen enters into it, I find that 4 volumes of deutoxide combine with 1 volume of oxygen, and form an acid, which is absorbed by the water. Now, 4 volumes of deutoxide are composed of 2 volumes azotic and 2 volumes oxygen gases. Hence, the acid formed, is a compound of 2 volumes azotic and 3 volumes oxygen gases; or of 1 volume azotic and 1.5 volumes of oxygen gas, or by weight of

Azote . . 0·9722 or 1·75
Oxygen . . 1·6666 or 3.

Now, this is the acid to which the name of *hyponitrous* has been given. We see from its composition, that supposing the weight of azote in each the same, hyponitrous acid contains thrice as much oxygen as protoxide of azote.

This acid can exist only in combination. All the salts for- merly called *nitrites* are in fact combinations of this acid with a base. Gay-Lussac showed that it is formed whenever deutoxide of azote is left for some time in contact with a powerful base. He left for three months 100 volumes of deutoxide in contact with a solution of pure potash over mercury. At the end of that time the gas was reduced to 25 volumes, which turned out on examination to be pure protoxide of azote. The potash was found partly combined with an acid, which was obviously the hyponitrous. For 100 volumes of deutoxide of azote, are composed of

Volumes.   Volumes.
50 azote + 50 oxygen.

While 25 volumes of protoxide of azote are composed of

Volumes.   Volumes.
25 azotic + 12·5 oxygen.

If we subtract this quantity from the original volumes of azote and oxygen in the deutoxide, we shall have the volumes of azote and oxygen constituting the acid which has combined with the potash. These are

Volumes.   Volumes.
25 azotic + 37·5 oxygen, or, (multiplying by 4)
100   + 150

precisely the same as the acid formed directly by the union of oxygen gas with deutoxide of azote.

Whenever an excess of deutoxide of azote, mixed with oxygen gas, is placed in contact with a powerful base, hyponitrous acid is immediately formed and combines with the base, while pure deutoxide of azote remains. Thus, if we mix together 6 volumes of deutoxide of azote, and 1 volume oxygen gas, over a solution of pure potash in water, two volumes of deutoxide will remain; and 4 volumes of deutoxide, combining with 1 volume of oxygen, will form hyponitrous acid as before explained.

Hyponitrous acid combines readily with bases, and forms a genus of salts called *hyponitrites;* but it does not seem capable of existing in a separate state, either pure or in combination with water. When we attempt to separate it from a base it is immediately resolved into nitrous acid and deutoxide of azote.

4. Nitrous acid.

(4.) If we take a quantity of pure crystallized nitrate of lead, and after drying it for some time in a temperature of about 300°, reduce it to powder, and introduce it into a small bottle glass retort. By way of receiver, a bent glass tube in the form of a *u* may be used, terminating in the farthest extremity in a capillary opening, and luted at the other to the beak of the retort. The curvature of this tube should be surrounded by a mixture of snow and salt, to keep it at the temperature of zero. A heat gradually raised almost to redness, is necessary to disengage the nitric acid from the nitrate of lead. This acid not meeting with any water with which it can combine, and not being capable of existing in an insulated state, is immediately decomposed into oxygen and *nitrous acid.* The oxygen gas makes its escape from the capillary end of the tube, and the nitrous acid condenses in the curvature into a liquid.

Properties.

The taste of this liquid is very caustic; its smell is very strong, and its specific gravity 1·451. Its colour depends upon its temperature; at 60° it is orange yellow; at 32° it is fawn coloured, almost colourless at 14°, and quite colourless at — 4°. It reddens litmus paper, stains the skin orange, and at the same time, destroys its texture. It boils at 82°·5, and assumes the form of an orange red vapour. In this state, it was examined by Dr. Priestley, and called by him *nitrous* vapour.

It is not acted on by any of the supporters of combustion.

But it is decomposed by many combustible substances, as is the case with nitric acid itself. Water decomposes it instantly, and converts it into nitric acid and deutoxide of azote, which is disengaged, if the quantity of acid be small compared with the water, but remains in solution, tinging the nitric acid brown, yellow, or green, if the quantity of acid be considerable.

This acid does not seem capable of combining with bases. No nitrites. Hence there is no genus of salts to which the term *nitrite* can, with propriety, be applied. When we attempt to unite nitrous acid with a base, it is immediately resolved into nitric and hyponitrous acids, both of which unite with the base, constituting at once a nitrate and a hyponitrite. This decomposition is beautifully exemplified, when the vapour of nitrous acid is made to pass over dry barytes. The acid is absorbed slowly at the ordinary temperature of the air; but at 392°, the absorption is very rapid; the barytes becomes red hot and nitrate, and hyponitrite of barytes are formed. Similar phenomena are produced with other bases. With liquid ammonia, nitrate of ammonia is formed, while deutoxide of azote and azotic gas are disengaged. The reason of this is, that hyponitrite of ammonia is decomposed when it comes in contact with water.

Dulong analyzed this acid by causing its vapour to pass Composition slowly through red hot copper or iron turnings. The azotic of nitrous acid. gas was collected over mercury, after being dried, by passing it through a tube filled with chloride of calcium. The augmentation of weight of the copper or iron, gave the quantity of oxygen, while, from the bulk of azotic gas, the quantity of that constituent was determined. The azotic gas was mixed with a small quantity of hydrogen gas, not exceeding three per cent. and obviously derived from some traces of moisture in the vessels, from which it was very difficult to free them. In one experiment, of which he gives us the details, the quantity of acid decomposed was 122·55 grains. The iron filings increased in weight 87·41 grains. This was the oxygen contained in the gas, amounting at 60° to 252·6 cubic inches. The volume of azotic gas at 32°, was 1·93 litres, which is equivalent to 124·5 cubic inches of azotic gas, at the temperature of 60°, and when the barometer stands at 30 inches.* Thus, it appears, from Dulong's analysis, that nitrous acid is composed of

* Ann. de Chim. et de Phys ii 317.

	Volumes.
Oxygen . .	252·6 or 2·02
Azotic . .	124·5 or 1

This approaches so nearly to 1 volume of azotic gas, and 2 volumes of oxygen gas, that we can have no hesitation in adopting these proportions as indicating the true composition of this acid.   Indeed, Gay-Lussac had already determined its constituents with rigid accuracy in the following manner.   A globular glass vessel, capable of containing 400 cubic inches, was exhausted of air, and 200 cubic inches of deutoxide of azote were let into it.   It was then, by means of a stop-cock, placed in contact with a jar filled with oxygen gas.   The deutoxide is converted into nitrous acid, and 400 cubic inches of oxygen gas have entered the globular vessel, and, of course, either combined with the deutoxide, or replaced the vacuum, which would have otherwise taken place, in consequence of the union of the two gases.   If we now reverse the experiment, by putting 100 cubic inches of oxygen gas into the globular vessel, and then place it in contact with deutoxide of azote, nitrous acid is again formed, and 500 cubic inches of deutoxide of azote enter the vessel.   It is obvious, from these two experiments, that, in order to form nitrous acid, 200 volumes of deutoxide had combined with 100 volumes of oxygen, and that the volume of the nitrous acid (supposing it to remain in the elastic state) is precisely the same as that of the deutoxide, from which it was formed, or that the oxygen gas enters into combination with it, without increasing its volume.   Hence the specific gravity of nitrous acid vapour must be 1·5972. However, Dulong has shown that it is not, properly speaking, a gas, being easily condensed into a liquid when exposed to a mixture of snow and salt.   We see from this experiment of Gay-Lussac, that nitrous acid vapour is composed of

1 volume azotic gas,   ⎱ condensed into 0·75 volume.   This
2 volumes oxygen gas,   ⎰ is the same thing by weight, as

Azote . .	0·9722 or 1·75
Oxygen . .	2·2222 or 4 ""

What view are we to take of nitrous acid?   It has been shown to be incapable of uniting to bases.   When we make the attempt, we obtain nitrate and hyponitrite, as was first shown by Gay-Lussac.   Is it not probable, from this, that nitrous acid is not a true acid, but merely a mixture or compound of 1 integrant particle of hyponitrous acid, and 1 integ-

rant particle of nitric acid? This view of its nature is simpler, and accords better with the analogy of other bodies, than the supposition that it is a peculiar compound of oxygen and azote.

(5.) Chemists are agreed respecting the composition of nitric acid. It has been shown by experiments, which are perfectly decisive, that it is a compound of

Azotic gas   .   .   1 volume,
Oxygen   .   .   2·5 volumes,

I attempted to reduce this acid into oxygen and azotic gases, by exposing nitric acid to a red heat; but never succeeded in obtaining satisfactory results. Nor were the results satisfactory when saltpetre and charcoal were mixed and ignited; but with iron filings, mixed with a certain quantity of saltpetre, in a copper tube, and exposed to a red heat, the result was more satisfactory. 8·65 grains of saltpetre, treated in this way, gave out very nearly 4 cubic inches of azotic gas; hence, 2·1625 grains of saltpetre would have given out about 1 cubic inch of this gas; but 2·1625 grains of nitre contain 1·144852 grains of nitric acid; a cubic inch of azotic gas 0.302794 grain. Hence the weight of oxygen gas, in this quantity of nitric acid must be 0·842058 grain. This (supposing the temperature 60°, and the barometer at 30 inches) is equivalent to 2·43 cubic inches.* Hence, according to this experiment, nitric acid is composed of

1 volume azotic gas,
2·43 volumes oxygen gas.

Gay-Lussac demonstrated, by a very simple experiment, that the true constituents of this acid are 1 volume of azotic, and 2·5 volumes of oxygen gas. Into a tube, filled with water, he introduced a given volume of deutoxide of azote, and added to it an excess of oxygen gas; taking care not to agitate the tube. The two gases united, and formed nitrous acid, which, being absorbed by the water, was decomposed into nitric acid and deutoxide of azote. This last gas being disengaged from the water, united with a new dose of oxygen gas, and formed nitrous acid. This new acid was again absorbed by the water, and again decomposed into nitric acid and deutoxide of azote, which was again disengaged. These combinations were repeated, till ultimately the whole was converted into nitric acid. We can determine whether the product of this experiment be pure nitric acid by mixing a little red sulphate of manganese with the water. This salt is not altered by nitric acid; but

* First Principles, i. 110.

nitrous acid instantly renders it colourless. Gay-Lussac found, that when 200 volumes of deutoxide of azote were, in this way, converted into nitric acid, the oxygen gas absorbed amounted to 150 volumes, or 100 volumes of deutoxide of azote, are converted into nitric acid by uniting with 75 volumes of oxygen gas. Hence, (since 100 volumes deutoxide contains 50 volumes azotic and 50 oxygen,) nitric acid is composed of

> 50 volumes azotic,
> 125 volumes oxygen gas, or of
> 1·0 volume azotic gas,
> 2·5 oxygen gas.

Hence, nitric acid is composed, by weight, of

> Azote　　.　　.　　0.9722, or 1·75
> Oxygen　.　　.　　2·7777, or 5.

Composition of the compound of azote and oxygen. From the account of the constitution of the five compounds of oxygen and azote, which we have now finished, it appears, that if we consider the constituents, as in the gaseous state, their relative proportions will be as follows:

	Azotic.	Oxygen.
Protoxide of azote	. 1 volume	+ 0·5 volume
Deutoxide of azote	. 1	+ 1
Hyponitrous acid	. 1	+ 1·5
Nitrous acid	. 1	+ 2
Nitric acid	. 1	+ 2·5

If we take the weights of the constituents only into view, the constituents of these compounds will be represented as follows:

	Azote.	Oxygen.
Protoxide of azote . . .	1·75 +	1
Deutoxide of azote . . .	1·75 +	2
Hyponitrous acid . . .	1·75 +	3
Nitrous acid . . .	1·75 +	4
Nitric acid	1·75 +	5

From this table, we see that if the weight of azote in these compounds be represented by 1.75, then the weight of oxygen in each increases as the natural numbers. Hence, it is obvious, that either 1·75, or some multiple, or submultiple of 1·75, must represent the atom of azote.

Atom of azote. Chemists have not yet agreed about the number which represents the atom of azote. The difference of opinion depends upon the view taken of the constitution of water. Those chemists who consider water as a compound of 1 atom

hydrogen, and 1 atom oxygen, draw, as a necessary conse-
quence, that half a volume of oxygen gas is equivalent to an
atom, while a whole volume of most other gases represents
an atom. Those who have adopted these opinions, represent
the atom of azote by the number 1·75. We consider the 5
compounds of azote and oxygen, as composed of 1 atom azote,
united with 1, 2, 3, 4, and 5, atoms of oxygen.

But those chemists who consider water as a compound of
2 atoms hydrogen, and 1 atom oxygen, naturally deduce the
number of atoms in each compound from the number of volumes
of each constituent. Deutoxide of azote being composed of 1
volume azotic, and 1 volume oxygen gas, they consider it as a
compound of 1 atom azote + 1 atom oxygen. Hence the
atomic weight of azote will be 0·875, and the composition of
the various compounds will be as follows :

			Azote.	Oxygen.
Protoxide of azote	.	.	2 atoms +	1 atom.
Deutoxide of azote	.	.	1 atom +	1
Hyponitrous acid	.	.	2	+ 3
Nitrous acid	.	.	1	+ 2
Nitric acid	.	.	2	+ 5

I have, in the preceding chapter, given the reasons which
have induced me to adopt the opinion, that water is a compound
of 1 atom hydrogen + 1 atom oxygen. Hence, the atom of
azote must be 1·75. This view of the subject, which is by far
the simplest, has been adopted by all British chemists, so far
as I know, except Mr. Dalton, whose objections are founded
not upon the constitution of water ; but, upon other considera-
tions, which, though very ingenious, cannot be considered as
conclusive. Berzelius having adopted the notion, that water
contains 2 atoms of hydrogen, has naturally taken 0·875 (or a
number deviating but little from this) for the atom of azote ;
and in this he has been followed by several of the German
and French chemists. But the system of atoms founded upon
this basis is so very complex, that it would be a thousand pities
to see it universally adopted. It wraps a very plain subject in
a mysterious veil, and seems to me rather calculated to retard
than promote the progress of chemistry as a science.*

* It is to be regretted that the names of these compounds of azote and
oxygen had not been rendered more systematic. Chaptal attempted to
make them so, by substituting the term *nitrogen* for azote, and this mode
of naming has been adopted by many chemists. It would have been better
had *azotous* and *azotic* been substituted for *nitrous* and *nitric* acid. Perhaps
this might still be done.

Chloride of
azote.

III. Azote has the property likewise of combining with chlorine, and of forming a very singular compound, to which we may give the name of *chloride of azote.*

History.

It seems to have been discovered about the beginning of 1812, by M. Dulong, who did not however publish any thing on the subject, having been deterred by two severe accidents, which prevented him from completing his investigation. In September, 1812, Sir H. Davy received a letter from M. Ampere, in which he mentions the discovery, without saying any thing about the mode of preparing it. This information roused his curiosity, and induced him to set about a series of experiments in order to obtain it. But before he had proceeded far, Mr. Children put him in mind of an oily substance, that had been observed about a year before by Mr. Burton, at Cambridge, when he passed a current of chlorine through a solution of nitrate of ammonia. This information enabled Davy to procure the substance, and to investigate its properties.* A very numerous set of experiments was made upon it about the same time, by Messrs. Porrett, Wilson, and Rupert Kirk.† There was lastly an abridgment of Dulong's original paper, drawn up and published by Thenard and Berthollet.‡ The chloride of azote may be procured in the following manner.

Preparation.

Dissolve in water of about 110°, a quantity of nitrate of ammonia, or sal ammoniac, so as to make a moderately strong, but not saturated solution. Put it into a flat dish, and invert over it a phial or cylindrical glass jar, previously filled with chlorine gas. The gas is slowly absorbed; a yellowish oily looking matter collects on the surface of the liquid within the jar, and gradually falls to the bottom. It is the *chloride of azote.* Care must be taken not to collect more at one time than a globule or two; and no experiments ought to be made upon a quantity of it, exceeding a grain in weight. For the explosions which it occasions are so violent as to be dangerous, unless the quantity employed be very small. Chloride of azote possesses the following properties.

Properties.

Its colour is nearly similar to that of olive oil. It is as transparent, and has little or none of the adhesiveness of oils. Its smell is peculiar and strong, though not so disagreeable nor injurious to the lungs, as that of chlorine.‖ It is very volatile,

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* Davy, Phil. Trans. 1813, pp. 1 and 24.
† Nicholson's Journal, xxxiv. 180 and 276. March and April, 1813.
‡ Ann. de Chim. lxxxvi. 37.
‖ Davy compares it to the smell of phosgene gas.

and is soon dissipated when left in the open air. It may be distilled over at 160° without danger; but is partially decomposed by the heat. The temperature of 200° only increases the rapidity of its evaporation; but when heated to 212°, it explodes with prodigious violence. In a vacuum it is converted into vapour, and is again condensed into a liquid when the pressure of the atmosphere is restored. If this vapour be heated sufficiently, it explodes with as much violence as the liquid itself.* The specific gravity of chloride of azote is 1·653.† When exposed to cold, the water in contact with it congeals at about 40°, but it remains fluid itself, though exposed to the cold produced by a mixture of ice and muriate of lime.‡

When left in water it speedily disappears, while a quantity of azotic gas is disengaged. When put into strong muriatic acid, a quantity of gas is extricated, considerably exceeding the whole weight of the chloride. This gas is chlorine; muriate of ammonia remains in the solution.

When chloride of azote comes in contact with phosphorus or oils, a violent detonation immediately takes place; the effect is so instantaneous and so great, that it has not been possible to collect the products. Messrs. Porrett, Wilson, and Rupert Kirk, brought 125 different substances in contact with it. The following were the only ones which caused it to explode.§

Supersulphuretted hydrogen	Oil of tar
Phosphorus	Oil of amber
Phosphuret of lime	Oil of petroleum
Caoutchouc	Oil of orange peel
Myrrh	Naphtha
Phosphuretted camphor	Soap of silver
Palm oil	Soap of mercury
Ambergris	Soap of copper
Whale oil	Soap of lead
Linseed oil	Soap of manganese
Olive oil	Fused potash
Camphoretted olive oil	Solution of pure ammonia
Sulphuretted olive oil	Phosphuretted hydrogen gas
Oil of turpentine	Nitrous gas.

Metals, resins, sugar, most of the gases did not explode with this substance.

M. Dulong placed chloride of azote in contact with pieces

* Porrett, Wilson, and Rupert Kirk.   † Davy.
‡ Davy.   This temperature was probably as low as — 40°.
§ Nicholson's Journal, xxxiv. 277.

of copper. The chloride disappeared, azotic gas was disengaged, and there was formed a solution of muriate of copper.* From this experiment it follows, that the substance is a compound of azote and chlorine. Davy found, that when it was exploded in an exhausted vessel, the only products were chlorine and azote.† This farther corroborates the nature of its constituents. When made to act upon mercury, a mixture of calomel and corrosive sublimate‡ is formed, and azote disengaged. In one experiment 0·7 grain of the chloride produced 49 grain measures, or 0·193 cubic inch of azote. This quantity weighs 0·058 grain. According to this estimate the chloride is composed of

$$
\begin{array}{lr}
\text{Azote} & 58 \\
\text{Chlorine} & 642
\end{array}
$$

This is equivalent to

1 volume azotic gas,
4·26 volumes chlorine gas.

As it is very difficult in such an experiment to collect the whole of the azotic gas, the probability is, that the chloride of azote is a compound of 1 volume of azotic gas, and 4 volumes of chlorine. Now, as in these two gases, volumes are equivalent to atoms, it would follow that the chloride is a compound of

$$
\begin{array}{lr}
\text{1 atom azote} & 1\cdot75 \\
\text{4 atoms chlorine} & 18 \\
\hline
& 19\cdot75
\end{array}
$$

Hence, the weight of its atom must be 19·75.

This substance possesses very little permanence; being instantly decomposed by phosphorus and oils, and pretty rapidly by water. Whether it possesses acid or alkaline characters is not known; nor could it be easily ascertained in consequence of the formidable nature of the compound.

IV. Hitherto chemists have made no successful attempts to form a compound of bromine and azote. When bromine is placed in contact with ammoniacal gas, the gas is absorbed, azotic gas evolved, and hydrobromate of ammonia formed. These changes are accompanied by the evolution of heat, but not of light, and no substance analogous to a chloride of azote makes its appearance.§

* Ann. de Chim. lxxxvi. 59.　　† Phil. Trans. 1813, p. 244.
‡ These are compounds of mercury and chlorine.
§ Balard; Ann. de Chim. et de Phys. xxxii. 358.

V. Azote has the property likewise of combining with iodine, and of forming a compound which may be called, *iodide of* *azote.* It was discovered by M. Courtois, and may be prepared in the following manner.

Put a quantity of iodine in powder into a solution of ammonia in water. It is converted into a brownish black matter which is the *iodide of azote.* It may be thrown while still moist, and mixed with the ammoniacal solution upon a filter. After the liquid has passed through the filter, while the iodide is still moist, the filter should be stretched flat on a board, and fixed firm to it by means of a little paste or gum water. For the powder when dry detonates violently, and with a violet coloured flame upon the smallest agitation of the paper. Indeed, I have often seen it explode spontaneously. This iodide has a brownish black colour, and has no smell whatever. If a solution of potash, or of hydriodate of ammonia be poured upon it, azotic gas is evolved, and the iodide decomposed. Even water causes an evolution of azotic gas though very slowly.

When iodine is placed in contact with ammoniacal gas, it is absorbed, and a shining viscid liquid of a blackish brown colour is formed, which when saturated with ammonia loses its viscidity. No gas is extricated during the formation of this compound, which seems to be an iodide of ammonia. It does not fulminate. When we dissolve it in water a portion of the ammonia is decomposed, and hydriodic acid and iodide of azote formed.

Iodide of azote when left in the open air gradually flies off in vapour without leaving any residue. It detonates with great violence when slightly touched, or when heated. If the detonation be performed in an exhausted glass vessel the only products are azotic gas and iodine.* Hence it is obvious that it is composed of these two substances. The attempts which have been made to determine the proportion of the constituents of this substance have not succeeded. Gay-Lussac calculates from theory† that it is a compound of one atom of azote and three atoms of iodine. But his mode of reasoning does not appear to me to possess much weight. If we knew the weight of the iodide from a given weight of iodine, or even the quantity of ammonia necessary to produce the change, some satisfactory

* Davy, Phil. Trans. 1814, p. 86.
† Ann. de Chim. xci. 30.

deductions might be made.　But at present, all the facts essential towards determining the ratio of the constituents of this
Composition. compound are wanting.　Gay-Lussac[*] states, but merely from theory, that when a gramme of this fulminating powder is decomposed, it yields 0·0864 litre of iodine vapour, and 0.0288 litre of azotic gas.　Hence 100 grains of the powder, should evolve of

Iodine vapour　　.　　.　　34·11 cubic inches
Azotic gas　　.　.　.　11.37

These quantities are small; yet the powder fulminates violently, in consequence of the rapidity of its decomposition.

Such are the properties of the combinations of azote, with the supporters of combustion, so far as they have been investigated.　It possesses the property likewise of combining with
Ammonia. hydrogen, and of forming an important compound called *ammonia*, the nature and properties of which we must now consider.

VI. Ammonia is usually prepared for chemical purposes from
Sal ammo-
niac.
sal ammoniac.　This term occurs both in Dioscorides[†] and Pliny;[‡] but from what these authors say respecting it, we are warranted to infer, that what the ancients indicated by that term, was merely a variety of common salt found in Cyrenaica and the neighbourhood.　The sal ammoniac of the moderns seems to have been first manufactured by the Arabians, and was made in Egypt (it is said from camel's dung) several centuries ago.　A manufactory of it (from soot and common salt) was established in Edinburgh by Dr. Hutton and Mr. Davy about the year 1760: and about the same period manufactories of it were established in France and other parts of Europe.

That sal ammoniac is a compound of muriatic acid and ammonia, was known to Tournefort in the year 1700.[§]　Geoffroy, junior, demonstrated the composition of the salt experimentally in the years 1716[||] and 1723.[¶]　And this was afterwards done with more precision by Duhamel in 1735.[**]　The mode of extracting carbonate of ammonia from sal ammoniac, by mix-

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[*] Ann. de Chim. xci. 31.　　　　[†] Dioscorides, lib. v. c. 75.
[‡] Plinii Hist. Mundi, lib. xxxi. c. 7.
[§] Mem. Paris, 1700, p. 71.　Tournefort knew that it is a compound of ammonia and an acid; but he does not say what the acid was.
[||] Hist. de l'Acad. 1716, p. 28.　　　　[¶] Ibid. 1723, p. 38.
[**] Mem. Paris, 1735, p. 106.

ing it with chalk, and distilling in a retort, was known to the alchymists; though little progress was made in investigating its properties. The difference between caustic ammonia and carbonate of ammonia, was first pointed out by Dr. Black. Dr. Priestley first shewed that pure ammonia is a gaseous substance, and pointed out the method of procuring it.

To obtain ammoniacal gas, reduce about half an ounce of sal ammoniac to powder. Introduce it into a small retort. Reduce about half an ounce of unslaked lime to powder. Introduce it into the same retort. Shake the two powders well, so as to mix them as intimately as possible. Then fill the whole belly of the retort with unslaked lime in powder. Plunge the beak of the retort under mercury, in the mercurial trough, and apply the heat of a lamp to the retort, the gas is evolved abundantly, and may be received in inverted glass jars filled with mercury. The first portions which come over, should be allowed to escape, to get rid of the common air which filled the beak of the retort. Ammoniacal gas thus procured, possesses the following characters.

Preparation of ammoniacal gas.

1. It is colourless, and possesses the mechanical properties of air. Its taste is acrid and caustic, and when drawn into the mouth it destroys the cuticle. When applied to any part of the body it acts as a rubefacient, and even blisters the part if long enough applied. Its smell is strong, pungent, and quite peculiar, and is well known under the name of an ammoniacal smell. Putrid urine exhales the same smell. Hence the odour of ammonia is often called urinous.

Properties.

2. Animals cannot breathe this gas. When they attempt to introduce it into the lungs, a spasm of the epiglottis takes place, which forcibly shuts the passage, and prevents any of the gas from making its way into the lungs.

3. The specific gravity of this gas, as determined by Davy, is 0·590164. I found it 0·59031; from a mean of three experiments made with great care. If we take the mean of these two results, we obtain 0·590237 for the specific gravity; which must be very near the truth. It will be shown afterwards, that this gas is a compound of 1 volume of azotic gas, and three volumes of hydrogen gas united together, and condensed into two volumes. Hence, if we add together the specific gravity of azotic gas, and three times the specific gravity of hydrogen gas, and divide the same by 2, we must obtain the true specific gravity of this gas.

Sp. gr. of azotic gas . . 0·9722
Sp. gr. of hydrogen, 0·0694 × 3=2683

$$\overline{2\mid 1{,}1805}$$

0·58027 = true specific gravity of ammoniacal gas. The specific gravity derived from experiment, is within less than $\frac{1}{10000}$th part of this number. There cannot then be any doubt that the specific gravity of the gas as derived from theory, is perfectly accurate.

4. If we reckon the refracting power of air 1, then that of ammoniacal gas, according to the experiments of Dulong, is 1·309.*

5. This gas acts powerfully on vegetable blue colours. Paper stained blue by the juice of red cabbage, or radishes, is rendered green. Paper stained brownish red by cudbear, is rendered deep violet. And paper stained yellow by turmeric is rendered brownish red.

6. Mr. Faraday demonstrated, that when subjected to sufficient pressure and cold, ammoniacal gas assumes the liquid form. Dry chloride of silver has the property of absorbing this gas in considerable quantity; a grain of the chloride absorbing about $1\frac{1}{4}$ cubic inch of the gas. Mr. Faraday put a quantity of chloride of silver impregnated with ammoniacal gas into a strong glass tube, which was then closed hermetically. Heat was applied to the extremity containing the chloride of silver, while the other extremity was kept cool by snow. The chloride entered into fusion, and gave out the ammoniacal gas, which was thus contained in the tube in a state of great compression. It condensed into a colourless liquid in the cold extremity of the tube. Liquid ammonia is very fluid. Its refracting power is greater than that of water, and its specific gravity is 0·76. At the temperature of 50° it exerts a pressure equivalent to $6\frac{1}{2}$ atmospheres.†

Liquid ammonia.

7. This gas is very rapidly absorbed by water, while at the same time the temperature of the liquid increases very much. By passing a current of ammoniacal gas through 6 cubic inches of water, contained in a small Wolfe's bottle, I found that the liquid absorbed 780 times its volume of the gas, while at the same time the bulk of the water increased from 6 to 10 cubic inches. Hence a cubic inch of water, saturated with this gas, contains 468 cubic inches of ammoniacal gas. But when in

*Ann. de Chim. et de Phys. xxxi. 166. † Phil. Trans. 1823, p. 196.

this state, it is so volatile that it cannot be preserved.   It is in
this state of solution in water that ammonia is commonly used
for chemical purposes.   The easiest method of preparing it, is
to put into a retort a mixture of about equal weights of quick-
lime and sal ammoniac.   The lime should be previously slaked
and in powder.*   The sal ammoniac should also be in powder.
The retort should then be filled about half full of water,
placed in a sand pot, and its beak luted to a Wolfe's bottle A,
having a little water at its bottom, and having two mouths *a*
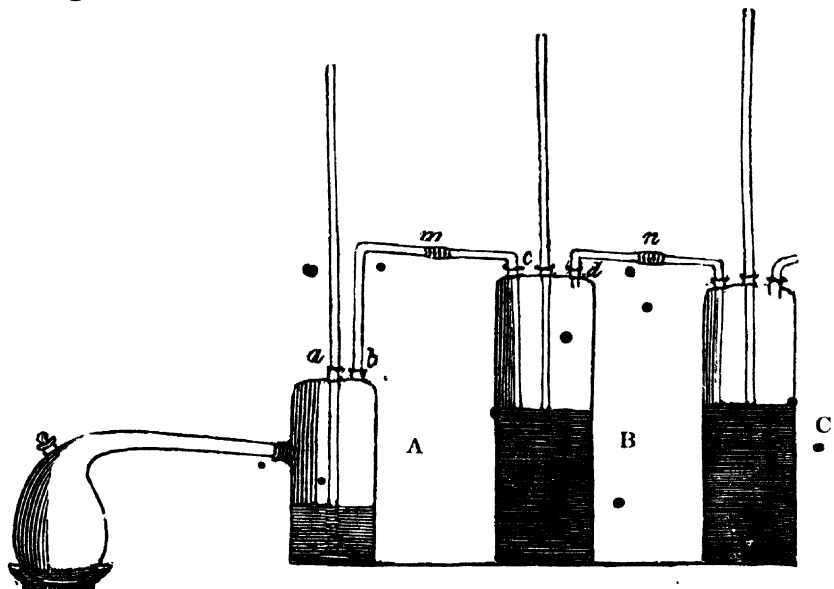
and *b*.   Through the mouth *a* passes a straight glass tube
through a perforated cork, so as to be air-tight.   The bottom
of this tube plunges into the water at the bottom of the jar,
which shuts up any communication between the inside of the
Wolfe's bottle and the external air.   From the second mouth
b a glass tube issues through a perforated cork.   This glass tube
after bending at right angles twice, passes into the mouth of
another Wolfe's bottle B with three tubulars, and half filled
with distilled water.   Through a perforated cork in the second
tubular *c* a straight tube passes, and reaches almost to the
bottom of the jar.   From the third tubular *d* another glass tube

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* The quantity of lime requisite to decompose 13·5 parts of sal ammoniac,
amounts to 7 parts.   When ammonia is prepared on a large scale, attention
should be paid to these proportions in order to save expense.   But in the
laboratory of the chemist, where the small quantity of surplus lime is no
object, I usually employ equal weights.

rises, and bending at right angles enters another Wolfe's bottle C, also half filled with water, and furnished with tubes precisely as the second bottle B.   The tubulars are all made air tight, first by perforated corks which firmly grasp the tubes, and are firmly grasped by the respective mouths of the bottles. Secondly, by fat lute laid on carefully.   And thirdly, by pieces of cotton cloth dipt in liquid glue, applied carefully to the mouths when moist, and tied firmly in their places by small cord.   The luting should be allowed to dry before the process commences.   The glass tubes m and n, if they consisted of one solid piece, could not be easily adjusted, and would be liable to be broken upon the smallest agitation of the apparatus.   To prevent this, they consist each of two pieces merely touching each other, at the points m and n.   They are tied firmly together by a ribbon of caoutchouc, previously moistened on one side by caoutchouc varnish, stretched firmly round the tubes, and fixed in its place by a string tied tightly round it.   Great care should be taken that the joints are all well luted, and quite air tight.   Heat is now applied to the retort. As soon as the water approaches the boiling temperature, ammoniacal gas is driven off in great abundance.   It soon fills the bottle A, and passing along the tube m is absorbed by the water in B, which becomes hot and gradually increases in bulk. If the process be continued till the water in B is saturated, the gas will pass through the tube n, and be absorbed by the water in the bottle C.   But it is better to stop the process before full saturation, because then the liquid is so volatile that it cannot easily be preserved.   The water in the bottle A, which distils over during the process, is also highly impregnated with ammonia, and if the distillation has been rightly conducted, it consists also of ammonia simply dissolved in pure water.   It should therefore be preserved for use as well as the water in the bottle B.*

Strength.

W.ater impregnated with ammonia by this process has the smell and taste and all the properties of ammonia in perfection. It is specifically lighter than water, and it is lighter in pro-

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* Mr. Payen recommends the preparation of ammonia from the sulphate instead of the muriate, on the score of economy, and Dumas says, that the price of the former is not even so much as one-fourth of the price of the latter.   I am not aware that sulphate of ammonia can be obtained at so cheap a rate in this country.   It might, however, be procured at a cheap enough rate from soot, and from the ammoniacal liquid obtained during the forming of coal gas.

portion to the quantity of gas which it contains. The following table, for which we are indebted to Mr. Dalton, exhibits the strength and the boiling point, and the quantity of ammoniacal gas in liquid ammonia of every specific gravity from the strongest to the weakest.*

Specific gravity.	Grains of ammonia in 100 gr. of the liquid.	Boiling point.	Volumes of gas in a volume of liquid.
850	35·3	26°	494
860	32·6	38	456
870	29·9	50	419
880	27·3	62	382
890	24·7	74	346
900	22·2	86	311
910	19·8	98	277
920	17·4	110	244
930	15·1	122	211
940	12·8	134	180
950	10·5	146	147
960	8·3	158	116
970	6·2	173	87
980	4·1	187	57
990	2	196	28

Davy found that the specific gravity of mixtures of liquid ammonia and water is exactly the mean of that of the two ingredients. And this observation was confirmed by Dalton. It is easy, therefore, if we can determine the specific gravity of a saturated solution, to determine the strength of liquid ammonia of every other strength.

8. When this gas is passed through a red hot porcelain or glass tube, it is decomposed into azotic and hydrogen gases.† When the tube is filled with wires of iron, copper, silver, gold, or platinum, the gas is much more easily decomposed than when it is exposed to a simple red heat. Iron is the most efficacious of these metals in promoting the decomposition of the gas, and platinum the least. The others are efficacious in the order in which they have been named. The iron by this process is rendered brittle, but its weight is not altered.‡ The reason of this decomposition being promoted by these metals is, that they have an affinity for hydrogen, with which they combine at a

Composition of ammonia.

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* New System of Chemistry, ii. 422. † Priestley on Air, ii. 395.
‡ Thenard; Ann. de Chim. lxxxv. 61.

particular temperature. But the compound being feeble is destroyed, and the hydrogen driven off when the temperature is elevated above the proper point. Hence the reason why the iron is left brittle. This has been shown to be the cause of the phenomenon by the late experiments of Despretz.

When ammoniacal gas is put into a glass tube, into which two platinum wires are hermetically sealed opposite to each other, and separated by a small interval, (the common eudiometer of Fontana will answer very well), as in the margin, and electrical sparks are passed through it, the gas undergoes decomposition. The tube must be placed inverted over mercury, and as the process is tedious, the quantity of gas should not exceed the tenth of a cubic inch. Both the gas and the mercury should be as dry as possible. This process was first attempted by Dr. Priestley, who ascertained that electric sparks occasioned a considerable increase in the bulk of the gas.* Berthollet repeated this process with the requisite care, showed that 1 volume of gas was increased 1·6 volumes, and that it consisted after the decomposition of 1 volume of azotic gas and 2·63 volumes of hydrogen gas.† Berthollet, junior, repeated these experiments, and showed that the volume of the gas was doubled, and that the new gas was composed very nearly of 1 volume of azotic gas and 3 volumes of hydrogen gas united together, and condensed into two volumes.‡ These experiments were repeated and confirmed by Dr. Henry§ and Sir H. Davy.|| And Gay-Lussac showed by satisfactory evidence, that the volumes of the constituents are exactly 3 hydrogen and 1 azotic gas condensed into two volumes.¶ So that no doubt whatever remains respecting the true constitution of ammonia. It is composed by weight of

$$\text{Hydrogen } 0·0694 \times 3 = 0·2083 \text{ or } 0·375$$
$$\text{Azote} \qquad\qquad\qquad 0·9722 \text{ or } 1·75$$

$$\overline{\qquad\qquad 2·125\qquad}$$

Hence it is a compound of three atoms of hydrogen and one atom of azote; and its atomic weight is 2·125. About the constitution of this body all chemists are agreed. But those gentlemen who consider water as a compound of 1 atom oxygen

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* Priestley on Air, ii. 389.   † See Mem. Paris, 1785, p. 136.
‡ Mem. d'Arcueil, ii. 268.   § Phil. Trans. 1809.
|| Chemistry, p. 269.   ¶ Mem. d'Arcueil, ii. 253.

and two atoms hydrogen, of course reduce the atomic weight of hydrogen to 0·0625, and that of azote to 0·875. Hence they consider the atomic weight of ammonia as only 1·0625, or a number approaching this very nearly.

Dr. Henry discovered that when ammoniacal gas is mixed with oxygen it detonates by the electrical spark. But when the quantity of oxygen necessary for consuming the whole hydrogen of the gas is added at first, there is formed by the explosion a quantity of nitric acid, which prevents us from determining the true composition of the ammonia. He proposes therefore to add to the ammoniacal gas at first, a smaller quantity of oxygen than is requisite, and to fire the mixture. To the residual gas, after the first detonation, an additional dose of oxygen is added, and the detonation repeated. Suppose we have 100 volumes of ammoniacal gas in the eudiometer, add 50 volumes of oxygen, and pass an electrical spark through the mixture. The oxygen will be entirely consumed. Add 30 additional volumes of oxygen and detonate again. Note the diminution of bulk. One-third of it denotes the oxygen consumed. This added to the first 50 volumes of oxyen used, will give the whole oxygen consumed, the double of that gives you the volume of hydrogen in the ammonia. This quantity subtracted from double the volume of the ammoniacal gas decomposed, leaves the volume of azotic gas.* I have tried this method and obtained tolerable approximations from it, but have not found it so exact as the tedious method of decomposing the ammonia by electricity.

But the action of chlorine on ammonia may be employed to give us the volume of azotic gas, which it contains with rigid exactness. It was first observed by Scheele that when chlorine and ammonia, each dissolved in water, are mixed together, azotic gas is disengaged and sal ammoniac formed. When these two bodies are mixed in the gaseous state, a sudden combustion, attended with detonation, takes place. If into a bottle holding two or three pints of chlorine gas we pour about a drachm of strong solution of ammonia, the two gases gradually mix and detonation takes place. But these phenomena, though curious and instructive, are not of a nature to give us correct information respecting the constitution of ammonia. But by means of the *chloride of lime* or *bleaching powder*, we may, by proper management decompose a quantity of ammonia united

* Phil. Trans. 1809.

to a base, and collect the whole azotic gas which it contains. The method of proceeding is the following. Fill the belly of a small retort with chloride of lime reduced by water to the consistency of cream. Introduce into it by the tubular 13·5 grains of dry sal ammoniac wrapt up in paper, put in the ground stopper, and rapidly plunging the retort into a trough of water drive out all the air from the beak. Then insert the beak into a small water trough, below an inverted glass jar filled with water. In a few minutes the paper, in which the sal ammoniac was wrapt, becomes sufficiently moist to fall off and leave the sal ammoniac exposed to the action of the chloride of lime. The ammonia is decomposed, and azotic gas is given out briskly. The mean of 7 experiments gave me 11·8 cubic inches of azotic gas from 13·5 grains of sal ammoniac. Now sal ammoniac is composed of

1 atom muriatic acid	. .	4·625
1 atom ammonia	. . . .	2·125
		6·75

Consequently 13·5 grains of it contain 4·25 grains of ammonia. Now 11·8 cubic inches of azotic gas weigh 3·57 grains. Hence ammonia is composed of

Azote	. .	3·57	or 1 volume
Hydrogen	. .	0·68	2·66 volumes
		4·25	

This result gives the quantity of azote rather in excess. This small excess was probably derived from the water, which had indeed been boiled; but which might, and probably did, absorb air from the atmosphere during the experiment. For 24 hours usually elapsed before the volume of azotic gas was determined.

9. There is a curious experiment for which we are indebted to Berzelius and Pontin, from which it has been concluded that azote is capable of uniting with 4 atoms of hydrogen, and of forming a compound to which the name of *ammonium* has been given. This ammonium is supposed to possess the characters of a metal. Sal ammoniac, according to Berzelius, is a compound of

1 atom chlorine	. .	4·5
1 atom ammonium	. .	2·25
		6·75

The atomic weight of ammonium is 2·25. The experiment upon Sect. II. which these conclusions depend is as follows.

Mercury, at the negative end of a galvanic battery, is placed in contact with a solution of ammonia, and the circuit completed. It gradually increases in volume, and, when expanded to four or five times its former bulk, becomes a soft solid. The experiment is easier, and the amalgam more permanent, if sal ammoniac slightly moistened be substituted for liquid ammo- Amalgam of. nia. Davy made a cavity in a piece of sal ammoniac slightly moistened, placed it on a plate of platinum attached to the positive end of the galvanic battery, put into the cavity about 50 grains of mercury, and brought in contact with the mercury a platinum wire attached to the negative end of the battery. A strong effervescence took place, much heat was evolved, and the globule in a few minutes had enlarged to five times its original bulk, and had the appearance of an amalgam of zinc. This amalgam, at the temperature of 70° or 80°, is a soft solid of the consistence of butter; at 32° it is a firm crystallized mass in which small facets appear, but having no perfectly defined form. Its specific gravity is below 3. When exposed to air it soon becomes covered with a white crust of carbonate of ammonia. When thrown into water, a quantity of hydrogen is evolved equal to half its bulk, the mercury is revived, and the water becomes a weak solution of ammonia. When confined in a given portion of air, the air increases considerably in volume, and pure mercury reappears. Ammoniacal gas amounting to $1\frac{1}{2}$ or $1\frac{3}{5}$ the volume of the amalgam is evolved, and a quantity of oxygen equal to $\frac{1}{7}$th or $\frac{1}{6}$th of the ammonia disappears. When thrown into muriatic acid gas it becomes coated with muriate of ammonia, and a little hydrogen is disengaged. In sulphuric acid it becomes coated with sulphate of ammonia and sulphur. All attempts made by Davy to preserve this amalgam failed, owing to the impossibility of freeing it entirely of water. When put into a glass tube, or when confined under naphtha or oils, the mercury separated, ammonia was formed, and a quantity of hydrogen evolved.*

The result of the experiments of Gay-Lussac and Thenard is, that this amalgam is a simple combination of mercury and ammonia. But we are not able to form such a combination by any other method than the one just described. Nor do we

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* Davy's Electro-chemical Researches on the Decomposition of the Earths, &c. Phil. Trans. 1808.

know any example of mercury being capable of amalgamating with any substance except a metal. When it unites with other bodies, as oxygen, sulphur, oils, &c. it always loses its metallic lustre. The nature of this amalgam is still involved in obscurity. The circumstance that when the amalgam is destroyed, ammonia and hydrogen gas are always evolved, and that these bodies, together with the mercury, equal the weight of the amalgam, gives some plausibility to the notion of Berzelius; but it cannot be considered as proved, and far less adopted as an established principle.

10. Ammonia possesses the characters of an alkali very decidedly. It neutralizes the acids, and forms with them salts, many of which are well known, and of considerable importance.

VII. It would be difficult to give a table of the order in which the different bodies which unite with azote, decompose these compounds. None of them can be considered as very intimate, since they can all without exception be destroyed by the application of a sufficiently strong heat. In this respect, they differ exceedingly from the compounds of hydrogen.

It is curious that the compounds of azote and oxygen are all supporters of combustion; while those of hydrogen and oxygen are not so.

VIII. Chemists have been inclined to consider *azote* as a compound, and many attempts have been made to decompose it, though without success.

SECTION III.—OF CARBON.

Carbon exists in immense quantities in the vegetable kingdom, and is easily obtained by heating *woods* in close vessels in a state of greater or less purity. It exists likewise in the earth in two distinct states, which are distinguished by the names of *anthracite* and *plumbago*. It occurs also in another state in which it is crystallized and transparent. In this state it is called *diamond.* There is still another state in which this substance exists seemingly in considerable purity. In this state it has been known only since the general use of coal gas to illuminate the streets. It may be called *coal gas charcoal.* It will be proper to give a short description of each of these different substances or states of *carbon*.

Wood charcoal of two kinds. 1. *Wood charcoal* may be obtained in two very different states, which it is necessary carefully to distinguish. If we put pieces of wood into a stone-ware retort, and expose to a heat nearly equal to that at which mercury boils, and keep it at that

temperature, till all vapours cease to be emitted, and then allow the whole to cool, we obtain a black shining mass having the shape of the pieces of wood employed; but much lighter. This may be called *charcoal*, formed at a temperature below 1st. Formed under a red ignition. It burns very well and very readily; but during the heat. combustion, it gives out both some smoke and some flame. It is a *non-conductor* of electricity, and cannot be employed as one of the elements of the galvanic pile. It is a very bad conductor of heat; so much so that one extremity may be lighted, while the other extremity is held in the hand.

2. If the heat be raised to redness, and kept at that temper- 2d. Formed ature till all smoke and vapour cease to be emitted, and then by a red heat. allow the retort to cool, the charcoal obtained is black, and as in the former case, has the shape of the pieces of wood from which it was formed. It is now an excellent conductor of electricity, and may be substituted for one of the metals in the galvanic pile. It is also a good conductor of heat, and not nearly so combustible as the first species of charcoal.* This second kind of charcoal may be called *charcoal* formed at a red heat. It is the species in common use, and is always understood when chemists speak of charcoal, unless the contrary be distinctly stated.

Charcoal for common purposes is most commonly made Common charcoal. from *birch*. The faggots are piled up into a kind of cone, and being covered with turf to exclude the air, except by a few small holes left open at the bottom. They are lighted, and in consequence of the small supply of air, burn with a smothered flame. As the combustion ascends, the holes at the bottom are closed up, and new ones opened higher up. When the cones cease to give out smoke and vapour, all the holes are shut, and the combustion put an end to. The process requires to be carefully watched, to prevent waste from too rapid combustion. The slower the process is conducted, the greater is the quantity of charcoal obtained. 100 lbs. of wood yield usually about 16 pounds of charcoal. But when the wood is ignited in a retort, the quantity of charcoal amounts to 28 per cent.

Charcoal is insoluble in water. It is not affected (provided Properties. that all air and moisture be excluded) by the most violent heat which can be applied, excepting only that it is rendered much

* See Cheuvreusse, Ann. de Chim. et de Phys. xxix. 426.

harder and more brilliant.* It is much less liable to putrify or rot than wood, and is not therefore so apt to decay by age. This property has been long known. It was customary among the ancients to *char* the outside of those stakes which were to be driven into the ground or placed in water, in order to preserve the wood from spoiling. New-made charcoal, by being rolled up in clothes which have contracted a disagreeable odour, effectually destroys it. When boiled with meat beginning to putrefy, it takes away the bad taint. It is perhaps the best teeth-powder known. Mr. Lowitz of Petersburgh has shown, that it may be used with advantage to purify a great variety of substances.†

When putrid water at sea is mixed with about $\frac{1}{9}$th of its weight of charcoal powder it is rendered quite fresh, and a much smaller quantity of charcoal will serve if the precaution be taken to add a little sulphuric acid previously to the water. If the water casks be charred before they are filled with water, the liquid remains good in them for years. This precaution ought always to be taken for long sea voyages. The same precaution, when attended to for wine casks, will be found very much to improve the quality of the wine.‡

New-made charcoal absorbs moisture with avidity. Messrs. Allen and Pepys found, that when left for a day in the open air, it increased in weight about $12\frac{1}{2}$ per cent. The greatest part of this increase was owing to moisture which it emitted again copiously when exposed under mercury to the heat of 214°.§

Absorbs gases.

When freed from the air which it may contain, either by heat or by being placed under an exhausted receiver, it has the property of absorbing a certain quantity of any gaseous body in which it may be placed. Lametherie made some experiments on this subject many years ago.‖ Count Morozzo made many curious observations on the quantity of different gases absorbed by charcoal.¶ These were varied and extended

* This property was well known to the older chemists. See Hoffmann's Observationes Physico-Chymicæ Selectiores, p. 298.

† See upon the properties of charcoal the experiments of Lowitz, Crell's Annals, ii. 165. Engl. Trans. and of Kels, ibid. iii. 270.

‡ Berthollet, Ann. de Chim. lix. 96 ; and xciii. 150.

§ Allen and Pepys on the quantity of carbon in carbonic acid. Phil. Trans. 1807.

‖ Jour. de Phys. xxx. 309.

¶ Jour. de Phys. 1783, p. 376. Nicholson's Journal, ix. 255, and x. 12.

still farther by Messrs. Rouppe and Van Noorden of Rotterdam.* But the most complete and satisfactory set of experiments on the absorption of gases, by charcoal, has been made by M. Theodore de Saussure.† His method was to eat the bit of charcoal red hot, to plunge it while in that state under mercury, and then to introduce it when cold into the gas to be examined. He always employed box-wood charcoal. The following table exhibits the bulk of the various gases absorbed by a volume of charcoal reckoned one :

	Volumes.
Ammoniacal gas	90
Muriatic acid	85
Sulphurous acid	65
Sulphuretted hydrogen . . .	55
Nitrous oxide	40
Carbonic acid	35
Olefiant gas	35
Carbonic oxide	9·42
Oxygen	9·25
Azote	7·5
Oxy-carburetted hydrogen‡ . .	5·
Hydrogen	1·75

The absorption of all these gases terminated at the end of 24 hours, and was not increased by allowing the charcoal to remain in contact with the gas. From Saussure's experiments it seems clear that this absorption of the gases, by charcoal, is analogous to the capillary attraction of liquids by very small tubes.

When charcoal already saturated with any gas is put into another gas, it gives out a portion of the gas already absorbed, and absorbs a portion of the new gas. The proportions vary according to the relative absorbability of the two gases.

Charcoal, supposing it to have been exposed to a sufficiently high temperature, contains very little else than carbon. If we burn it in a platinum tray, kept at a red heat, and exposed freely to the action of the atmosphere, a small quantity of white ash always remains. This consists partly of potash and partly of the various alkaline and earthy salts that exist in

Consists of carbon.

* Ann. de Chim. xxxii· 3.
† Annals of Philosophy, vi. 241, and 331.
‡ Gas from moist charcoal of the specific gravity 0·3326.

wood. The quantity of this ash varies in the charcoal obtained from different woods. When charcoal is burnt in close vessels, traces of water always appear, indicating the presence either of hydrogen or of water in the charcoal. From Davy's experiments, we learn that the quantity of hydrogen in well burnt charcoal is very small, as the water formed always totally disappears on standing, being not more than can assume the form of vapour, at the common temperature of the air in the volume of oxygen gas, necessary to consume the charcoal.

The specific gravity of charcoal, when taken in the usual way, appears small; for it floats in water. Yet if we reduce it to a fine powder it sinks readily in that liquid. When we take the specific gravity of charcoal by the method invented by M. Say,* and lately improved by Professor Leslie, which enables us to exclude all the cavities filled with air, and merely to estimate the bulk and weight of the solid portion, the specific gravity comes out about 3·5. Hence the apparent lightness is merely owing to the numerous cavities which the charcoal contains, and to which the water into which we plunge it cannot penetrate.

Anthracite. 2. The mineral called *anthracite* occurs most commonly in the *transition* formation, though there are well known examples of its occurrence in considerable quantity among the common coal-beds. Thus it occurs on the banks of Ayr river in Ayrshire. I suspect, too, that the *culm* of Wales occurs in the common coal beds, though I am not aware that its position has been accurately investigated. The Kilkenny coal in Ireland, which is a species of anthracite, occurs in the coal formation. There is a thick bed of anthracite in the state of Pennsylvania, extending above 100 miles in length, partly parallel to the Blue Mountains, and partly along the banks of the Susquehanna. The country, as Mr. Maclure informs us, is transition; but the beds, as described by Mr. Cist, and also the vegetable remains, are similar to those which occur in the common coal formation.† A similar bed of anthracite occurs in Rhode Island;‡ and another of great extent along the banks of the Arkansas, as we are informed by Mr. Bringier.§

Anthracite was called by Werner *glance coal* from its superior lustre. In this country it is known by a variety of names,

* Ann. de Chim. xxiii. 1.   † Silliman's Journal, iv. 1.
‡ Ibid. xi. 78.   § Ibid. iii. 41.

according to its locality or the use to which it is put.　That at Cumnock, and on the Ayr in Ayrshire, is commonly called *black lead*.　It is called *blind coal*, because it burns without flame; *foul coal*, when much contaminated with earthy matter.　Those varieties which admit of being cut into ornaments are called *jet*, and sometimes *pitch coal*.

The colour of anthracite is black, and its lustre usually splendent.　When the fracture is conchoidal the mineral is pale, and it approaches the colour of lead; when foliated the lustre is semimetallic, and it approaches the colour of copper. The specific gravity is about 1·4354.*　Some varieties are said to be as high as 1·5, or even higher; but I have not myself met with any specimens having a specific gravity so high as 1·5. Anthracite is easily broken and reduced to powder.　It burns without flame, and requires a high temperature to set it on fire. After the combustion there remains a small quantity of ashes, which constituted a foreign matter accidentally mixed with the anthracite.　From the experiments of Mr. Lardner Vanuxem it would appear, also, that water constitutes an ingredient in anthracite, doubtless only mechanically lodged in the pores of the mineral.　He analyzed a number of specimens of anthracite, and obtained the following results :†

1. *A very pure Lehigh specimen.*　　　　　　

Charcoal	. . . . . .	90·1
Water	. . . . . .	6·6
Ashes composed of ⎰ Silica	. . . .	1·2
Alumina	. . . .	1·1
Oxides of iron and manganese		0·2
		99·2

2. *Rhode Island Anthracite.*

Charcoal	. . . . . .	90·03
Water	. . . . . .	4·90
Ashes ⎰ Silica	. . . . .	2·14
Oxides of iron and manganese	.	2·50
		99·57

* This is the specific gravity of Kilkenny coal.　See Annals of Philosophy (1st series), xv. 394.
† Silliman's Journal, x. 102.

3. *Another Rhode Island specimen.*

Charcoal	. . . . . .	77·7
Water	. . . . . .	6·7
Ashes { Silica	. . . . .	8·5
Alumina trace, oxides of iron and		
manganese	. . . .	7·1
		——
		100·0

I analyzed Kilkenny coal by heating it with black oxide of copper, and collecting the carbonic acid formed. One grain of the coal thus treated yielded 7·06 cubic inches of carbonic acid gas, which is equivalent to 0·913 grain of carbon. One grain of the coal when burnt completely, left 0·04 grain of a reddish brown earth, consisting of a mixture of silica and oxide of iron. Hence the constituents of Kilkenny coal were,

Carbon	. . . .	91·3
Ashes	. . . .	4·0
		——
		95·3

The loss amounting to 4·7 per cent. I ascribed to the presence of oxygen in the coal. It could not have been owing to hydrogen, otherwise water would have been formed. Had it been owing to azote, a mixture of that gas with the carbonic acid in the receiver would have been detected.* If the loss be really oxygen, then Kilkenny coal is a compound of

1 atom oxygen =	1
26 atoms carbon =	19·5
	——
	20·5

3. *Plumbago.* This mineral occurs in detatched masses in primitive rocks, gneiss, mica-slate, granular lime-stone, and serpentine. It occurs also in greenstone and amvgdaloid, though much less frequently. We have no sufficient evidence that the ancients were acquainted with it. But it has been employed for the manufacture of black lead pencils for at least three centuries. The plumbago mine at Borrowdale in Cumberland began to be wrought during the reign of queen

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* See Annals of Philosophy, xv. 394.

Elizabeth. This is the mine which yields the only plumbago known to answer for making black lead pencils; though I have been told by some pencil makers, that Spanish plumbago is also used for the same purpose.

Werner gave *plumbago* the name of *graphite*, in consequence of its use in the manufactory of pencils. In this country it is usually called *black lead*. It was not distinguished from *molybdena* till Scheele's experiments upon it became known to the chemical world.

Plumbago is a soft mineral having a greasy feel, the metallic lustre, and a colour approaching that of iron. It is sectile and rather tough. It sometimes exhibits a foliated texture, while sometimes no such texture can be distinguished. It is said to have been met with crystallized in six-sided prisms, with a cleavage parallel to the base of the prism. Its specific gravity varies from 1·9 to 2·32. Like charcoal it is a conductor of electricity. When strongly heated it consumes away without flame, leaving usually a yellow coloured ash. When thrown into saltpetre, previously heated to redness, it deflagrates with it as violently as charcoal does. From the experiments of Davy it appears, that when burnt in oxygen gas, not only carbonic acid but a little water is also formed. But the quantity of water is very small, being less than is yielded even by wellburnt charcoal. Hence plumbago consists essentially of carbon. The ash which remains, and which is obviously a foreign substance, varies very much both in its quantity and constitution, as will appear from the following analyses of different varieties of this mineral.

I. *Specimens analyzed by Mr. Vanuxem.**

Carbon	88·37	61·27	95·4
Water	1·23	5·33	0·6
Silica	5·10	10·10	2·6
Alumina	1·00	3·20	——
Oxides of iron and manganese	3·60	20·00	1·4
	99·30	99·90	100·0

* Silliman's Jour. x. 105. The first specimen was from Borrowdale, and very pure. The second from the same locality, but impure; the third was a very pure specimen from Bustletown, Pennsylvania.

II. *Specimens of ashes from English and Spanish Plumbago, analyzed by Schräd r.*[*]

200 grains of the ashes of a compact graphite from Borrow-dale gave,

Protoxide of iron . . .	11·6
Silica . . .	7
Alumina . . .	4·6
Titanic acid . . .	6·3
	——
	29·5

200 grains of the ashes of a specimen of Spanish graphite gave,

Protoxide of iron . . .	14·2
Silica . . .	3·0
Alumina . . .	2·4
Oxide of copper . . .	1·0
Titanic acid . . .	3·1
	——
	23·7

It is obvious enough that the oxide of iron and alumina were in combination with the titanic acid and silica, and consequently that the opinion of Berthollet, that plumbago is a compound of carbon and iron, cannot be well-founded.

Diamond.

4. The diamond is a mineral which has been known and prized from the earliest ages on account of its beauty and scarcity. For many years it was obtained only in India, where it appears to occur in an alluvial soil, or in a sand-stone breccia composed of fragments of jasper, quartz, chalcedony, and hornstone, cemented together by a quartzose paste, passing into a puddingstone composed of rounded pebbles of the same substances, cemented by an argillo-calcareous earth.[†] Towards the beginning of the 18th century diamonds were accidentally discovered in the district of Cerro do Frio, in Brazil; and since that period they have been found in various other pro-

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[*] Annals of Philosophy, i. 294.
[†] This is Mr. Voysey's account of the structure of the Nalla Malla Mountains in Hindostan, where diamonds occur. See Phil. Mag. (2d series), i. 147.

vinces of that extensive country. It is from Brazil that by far
the greater number of diamonds for the European market come.
The localities in Brazil where diamonds are found are all allu-
vial. But from a specimen described by Mr. Heuland,* there
is reason to suspect that the real matrix of the diamond in that
country is a brown iron stone, which occurs in thick veins or
beds, resting on chlorite slate; and, therefore, either *transi-
tion* or *primary;* most likely the latter. It is said that dia-
monds have lately been discovered in Russian Siberia; but
no accurate information on the subject has yet reached this
country.

The diamond is usually white and perfectly transparent; Properties.
though it occurs also red, green, yellow, blue, and even black.
Its lustre is splendent, and so much superior to that of most
other bodies, that it is distinguished by the name of diamond
lustre. It is frequently crystallized. The primary form is
the regular octahedron, but it occurs also in cubes, and in
rhomboidal dodecahedrons. The faces are commonly curved.
The specific gravity varies from 3·4 to 3·6. The most usual
specific gravity is about 3·52. It is the hardest body in nature.
Its texture is foliated. It is broken by a blow without difficulty.
It refracts singly and more powerfully than other transparent
bodies of the same density; but incombustible. It is a non-
conductor of electricity.

This mineral was long considered as incombustible. But
Newton, from its property of refracting light so powerfully,
conjectured that it was capable of burning. This conjecture
was verified in 1694, in the presence of Cosmo III. Grand
Duke of Tuscany. By means of a burning-glass the Floren-
tine Academicians consumed several diamonds.† In 1751,
Francis I. Emperor of Germany, witnessed the destruction of
several more diamonds in the heat of a furnace.‡ These expe-
riments were repeated by Darcet, Rouelle, Macquer, Cadet,
and Lavoisier, who proved that the diamond was not merely
evaporated but actually burnt, and that if air was excluded it
underwent no change.§

Mr. Lavoisier prosecuted these experiments with his usual

* Geological Trans. (2d series), i. 419.

† Giornale de Litterati d'Italia, tom. viii. art. 9. The experiments were
performed by Averani.

‡ Das Neueste aus der anmuthigen gelehrsamkeit. Aus das Jahr, 1751,
S. 540.

§ Mem. Par. 1766, 1770, 1771, 1772.

precision; burnt diamonds in close vessels by means of power-ful burning-glasses; ascertained that, during their combustion, carbonic acid gas is formed; and that in this respect there is a striking analogy between them and charcoal, as well as in the affinity of both when heated in close vessels.* A very high temperature is not necessary for the combustion of the diamond. Sir George Mackenzie ascertained that they burn in a muffle† when heated to the temperature of 14° of Wedgewood's pyrometer; a heat considerably less than is necessary to melt silver.‡ When raised to this temperature they waste pretty fast, burning with a low flame, and increasing somewhat in bulk; their surface too is often covered with a crust of char-coal, especially when they are consumed in close vessels by means of burning-glasses.§

Composed of carbon.

In 1785, Guyton-Morveau found that the diamond is com-bustible when dropped into melted nitre; that it burns without leaving any residuum, and in a manner analogous to charcoal.‖ Mr. Smithson Tennant repeated this experiment with precision in 1797. Into a tube of gold he put 120 grains of nitre, and 2·5 grains of diamond, and kept the mixture in a red heat for half an hour. The diamond was consumed by the oxygen, which red-hot nitre always gives out. The carbonic acid formed was taken up by means of lime, and afterwards separated from the lime and measured. It occupied the bulk in one experiment of 10·3 ounces of water, and in another of 10·1: the mean is equal to 19·36 inches of carbonic acid, which have been ascertained to weigh 9·19 grains. Now 9·19 grains of carbonic acid contain 2·506 grains of carbon. This approaches so closely to the weight of the diamond burnt, that no doubt can remain, provided the experiment be accurate, that diamond consists of pure carbon.¶

The experiments of Lavoisier were repeated in 1800 by Morveau; but his experiments were inaccurate, as was after-wards admitted by himself; his consequences, of course, are entitled to no attention. The combustion of the diamond in oxygen gas was repeated in 1807, with every requisite precau-tion, by Messrs. Allen and Pepys, and their results agree very

* Lavoisier's Opuscules, ii. as quoted by Macquer. Dict. i. 337.
† A muffle is a kind of small earthen-ware oven, open at one end, and fitted into a furnace.
‡ Nicholson's Quarto Jour. iv. 104.
§ Macquer and Lavoisier. Macquer's Dict. Ibid.
‖ Encyc. Method. Chim. i. 742.   ¶ Phil. Trans. 1797, p. 123.

nearly with those of Tennant.* It has been repeated still
more lately by Sir H. Davy, with nearly the same result.† It
seems therefore demonstrated that the diamond and charcoal
are composed of very nearly the same basis.

5. The nature and state of the charcoal from coal gas is Coal gas char-
highly deserving of attention; because it is more likely than coal.
any thing else to throw light upon the origin of the diamond.
It is well known that coal gas is obtained by heating pit coal
in eliptical iron retorts till it ceases to give out gas. Very
soon there is a deposition of carbonaceous matter at the inner-
most extremity of the retort, which gradually extends itself 1st. Deposited
along the sides to the mouth, and increases in thickness in spite in the retort.
of all the endeavours of the workmen to prevent it. When
this crust gets to a certain thickness it occasions such a waste
of fuel, in consequence of its being a bad conductor of heat,
that the retort is obliged to be laid aside.‡ This crust has an
iron grey colour, with scarcely any lustre. It exhibits also
numerous patches of black, as if it were covered in these parts
with lamp-black. These indicate the position of the concentric
layers, and are composed of layers concentric with the walls of
the retort, though this structure is not easily perceived in the
pieces taken out of the retort. It is not hard, being easily
scratched by calcareous spar. It scratches crystals of sulphate
of lime. Streak black. It breaks with a smooth earthy frac-
ture. It is tough and not easily pounded, and requires a high
temperature to burn it. Specific gravity 1·860.

It is no uncommon thing in a gas manufactory for an iron 2d. Deposited
retort to crack. When this crack is small, and the escape of on a crack.
gas by it is small, it is still employed for distilling coal. In
such cases there is deposited on the inside of the case of brick-
work, in which the retort is coated, a beautiful mamillated
crust of carbon. Its colour is iron-grey, the lustre is splendent
and metallic. It seems composed of a kind of scales firmly com-
pacted on each other, and rising into imperfect columns some-
what like a stalagmite. It requires as high a temperature to burn
it as plumbago does. But it exhibits no appearance of containing
any other constituent than pure carbon. Its specific gravity
is 1·767. When held in the flame of a spirit lamp it becomes
red hot, but does not burn. By this process it loses a good

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* Phil. Trans. 1807.   † Ibid. 1814, p. 557.
‡ Probably its conducting power would be improved, if the retort con-
taining it were exposed for half an hour to as high a temperature as it could
bear without fusion.

deal of its lustre. It does not deflagrate with nitre unless it be strongly ignited. The deflagration is then very violent.

There is another appearance, which the carbon deposited from coal gas puts on still more remarkable. It was discovered, examined, and described with much skill and accuracy, by Dr. Colquhoun of Glasgow, and occurred during the trials of Mr. Macintosh of Crossbasket, to convert iron into steel, by surrounding it in a state of ignition with coal gas. To make these experiments, an air-tight iron chest was constructed, in which the specimens of iron to be steelified were placed. The chest was so placed in brick-work, that it could be kept in a state of ignition as long as was required. The gas was introduced by a tube, and the excess was allowed to make its escape, and burn away by means of a tube with a narrow orifice proceeding from the opposite side of the chest. There was a copious deposition of charry matter during the whole of these experiments; and the deposites put on a great variety of appearances; sometimes resembling lamp black, only harsher and harder to the feel; sometimes resembling the deposites in the inside of the iron retorts. But by far the most remarkable deposite was under the form of beautiful tufts of long capillary threads lying close together like a lock of hair. These threads varied in length from one inch to eight inches or more. They varied also in thickness from that of the hair of a horse's mane to the finest filaments of a spider's web. The colour was black, and the lustre splendent. These hairs cannot be bent without breaking, but they possess considerable strength considering their size. Dr. Colquhoun subjected them to a rigid analysis; but could detect in them nothing but carbon.* When held in the flame of a spirit lamp, they become strongly ignited; but do not consume nor lose their appearance. In nitre, strongly ignited, they deflagrate with great violence. All these three varieties of carbon are good conductors of electricity. When the second variety is deflagrated with nitre, it exhibits traces of iron; but the other two varieties contain none of that metal.

I suspect that the deposition of the carbon in these cases is connected with the affinity which exists between hydrogen and iron. Were we to admit that at a certain temperature hydrogen unites to iron, we could easily see why the carbon should be deposited, and why being in a state of the finest possible division, its particles should be at liberty to arrange themselves

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* Annals of Philosophy (new series), xii. 1.

symmetrically. The filamentous form which it assumes in such cases, probably depends upon the comparative slowness of the cooling, or on the comparative slowness of the decomposition of the gas. If we had any method of regulating the rapidity of these decompositions at pleasure, we should probably be able to procure regular crystals of carbon. The filamentous state is probably a commencement of crystallization. It is very analogous to asbestus. Now as asbestus is a peculiar variety sometimes of amphibole, and sometimes of pyroxene; perhaps some light might be thrown upon the subject by a careful examination of the situation in which asbestus is found, and the rocks with which it is associated.*

Of these five states in which carbon occurs, we have reason to believe, that it is purest or freest from all admixture of foreign matter in the diamond. The carbon from coal gas comes next in point of purity. If it contain any other constituent besides carbon, it must exist in very minute quantity. Anthracite, plumbago, and charcoal, are also very nearly pure carbon, if we abstract the earthy and metallic matters with which they are usually more or less mixed. They contain also traces of hydrogen or rather of water, from which it is very difficult to free them. A black colour and opacity are the usual characters of carbon; but we see from the diamond, that neither of these characters is essential. But when carbon is precipitated from gases, it usually appears under these forms.

Carbon combines with all the supporters of combustion; and likewise with hydrogen and carbon. Let us take a view of these combinations.

II. There are three combinations of carbon and oxygen known; namely, *carbonic acid, carbonic oxide,* and *oxalic acid.* The first and third, as the name implies, possess *acid* properties; the second is *neutral,* or at least has not hitherto been observed to have any tendency to combine either with bases or acids. Forms three compounds with oxygen.

1. It was known even to the ancients, that when charcoal is burnt in a given volume of air, though the fumes emitted are distinguished by no disagreeable smell; yet the nature of the air is so much altered, that animals can no longer breathe it without death. The nature of the change thus induced in the air, was first investigated by Lavoisier. He showed that when charcoal is burnt in air, or in oxygen gas, the bulk of the fluid 1. Carbonic acid.

* It is a curious enough circumstance; though I cannot account for it, that the asbestous form of minerals is connected with their occurrence in serpentine rocks.

is not altered.   When pure oxygen gas is employed, and a sufficient quantity of charcoal is burnt in it, by means of a burning-glass, the oxygen totally disappears, and is replaced by an equal volume of another gas, which had been previously examined by Mr. Cavendish, and which may be obtained abundantly, by dissolving calcareous spar or chalk in an acid, and collecting the gaseous fluid which is evolved.   Dr. Black, who first noticed this gas, called it *fixed air.*   But Lavoisier having found that it is equal to the weight of the oxygen gas, and carbon consumed, drew as a conclusion that it is a compound of carbon and oxygen; and, on that account, gave it the name of *carbonic acid.**

How obtained.   The easiest method of procuring carbonic acid gas is the following.   Put into the Wolfe's bottle *a,* having two mouths,
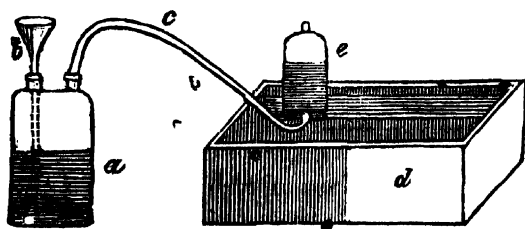
a number of fragments of limestone, or calcareous spar, each about the size of common beans.   Then fill the bottle about half full of water. The long funnel *b,* is then to be passed air tight through a perforated cork in one of the mouths of the jar, and made to pass to the bottom of the bottle.   From the other opening, the bent glass tube *c,* passes into the water trough *d,* and terminates under the mouth of the jar *e,* filled with water, and standing inverted upon the shelf of the trough.   A quantity of muriatic acid is then poured through the funnel *b* into the bottle; an effervescence takes place, carbonic acid gas is evolved in great abundance.   It passes along the glass tube *c,* and speedily fills the jar *e.*   We should not begin to collect it, till all the atmospheric air previously in the Wolfe's bottle and glass tube, has had time to make its escape.   If we put a solution of caustic potash into a glass tube, and let up a little of the gas into it from time to time, we will be sure that the carbonic acid gas is perfectly pure, when it is wholly absorbed by the potash.

Instead of muriatic acid, we may employ sulphuric acid; but in that case, the calcareous spar must be in the state of a fine powder, and the acid must be diluted with three or four times its bulk of water.   In such cases, we may substitute a retort for a Wolfe's bottle, and the extrication of the gas will

* Mem. Paris, 1781, p. 448.

be promoted by the application of a lamp to the belly of the retort; though such an application is not absolutely necessary.

The reason of this method of obtaining carbonic acid is this. Calcareous spar or limestone, is a compound of *lime* and *carbonic acid.* The muriatic or sulphuric acid combines with the lime, and sets the carbonic acid at liberty, which assuming the gaseous state, makes its escape from the liquid in an aërial form.

Carbonic acid is a gaseous body, possessing the mechanical Properties. properties of common air. It is invisible and colourless. But when applied to the nostrils, it excites a pungent sensation, similar to what is experienced when a glass of brisk beer or wine is held to the nose. Its taste is that of a weak, but distinct *acid.*

The first experimenters upon this gas gave its specific gravity below the truth, doubtless, because they were not at sufficient pains to free it from common air. According to Davy, 100 cubic inches at the temperature of 60°, and when the barometer stands at 30 inches, weigh 47·11 grains. This would make the specific gravity 1·5126. According to the determination of Biot and Arago, the specific gravity is 1·5196; according to Berzelius and Dulong, it is 1·5240. I found the specific gravity, by a mean of three trials, agreeing nearly with each other, 1·5267.* The true specific gravity, as I shall show immediately, is 1·5277.

Its power of refracting light, that of air being 1, is, according to the experiments of Dulong, 1·526.† So that it is nearly proportional to its increase of specific gravity above that of air.

Being an acid, we might expect that it would act upon vegetable blues. Its action, however, is but feeble. It produces no sensible effect upon water tinged blue by means of red cabbage. To the infusion of litmus it communicates a distinct purple colour. But if we leave the infusion in an open vessel the carbonic acid speedily escapes, and the blue colour is restored.

No animal can breathe this gas. When the attempt is made the epiglottis is forcibly shut, so that none of it can make its way to the lungs. This is speedily followed by asphyxia and death, unless the animal be instantly removed into pure air.

No combustible will burn in this gas. Indeed I find that if

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* Annals of Philosophy, xvi. 244.
† Ann. de Chim. et de Phys. xxxi. 166·

a candle be let down into a mixture of 9 volumes of air and 1 volume of carbonic acid gas, it is instantly extinguished.   Yet such a mixture might be breathed without any great inconvenience, at least for a short time.   Hence workmen should not descend into deep pits where this gas is apt to accumulate, without first ascertaining whether or not a candle will burn in it.

Absorption by water.   Water absorbs this gas with considerable avidity.   Hence though we can collect this gas for experiment over water, we must not allow the jars containing it to stand for any length of time over water, otherwise the whole of the gas will be absorbed and disappear.   From the experiments of Mr. Cavendish, it follows that 100 volumes of water are capable of absorbing under the ordinary pressure of the atmosphere 107 volumes of carbonic acid gas.   Hence it is usually said that water is capable of absorbing its own bulk of this gas.   When the gas by compression is reduced to one-half, or one-third its usual bulk, water, as Dr. Henry has shown,* still continues to absorb its own volume of it.   Hence by increasing the pressure we may make water absorb any quantity of it whatever.   What is called soda water, is water in which a little carbonate of soda has been previously dissolved, impregnated with about twice its volume of carbonic acid gas. . When the cork of the flask containing such water is drawn, the second atmosphere which is retained in a compressed state, suddenly makes its escape.   Hence the effervescence or briskness which such liquid displays.   The briskness of beer, of cyder, and of champaign, is owing to the existence of carbonic acid in them, in a compressed state.

If we let up a certain portion of carbonic acid gas into a tube filled with lime water, it becomes quite milky.   The reason is that the gas unites with the lime which the water holds in solution, and converts it into carbonate of lime, which, being insoluble in water, immediately begins to precipitate, and thus renders the liquid milky.   If we add twice as much carbonic acid gas to lime water as is requisite to precipitate the lime, the precipitate again disappears and the water becomes as transparent as at first.   The reason is, that lime unites with two proportions of carbonic acid.   With the smaller proportion it forms carbonate of lime which is insoluble in water, with the greater it forms bicarbonate of lime which is soluble in water.

* Phil. Trans. 1803,

When water impregnated with carbonic acid is heated, the gas is again expelled. From precipitated lime water it is not expelled by heat; from lime water rendered transparent by an excess of carbonic acid, that excess is expelled by heat, and then the carbonate of lime precipitates. It is in this way that carbonate of lime is held in solution in many mineral waters. Hence the reason why it is thrown down from them by boiling.

Mr. Faraday discovered that this gas assumes the liquid form when subjected at once to strong pressure and cold. But its elasticity is so great that the experiments are attended with some risk. His method of proceeding was this. A tube shut at one end was bent, and the shorter extremity, which was the sealed end, was filled with sulphuric acid through a tube, so as to keep the long leg of the tube quite clear. A piece of platinum foil was then crumpled up and pushed into the bend of the tube. Then the long leg of the tube was nearly filled with fragments of carbonate of ammonia. The other extremity of the tube was now sealed. The sulphuric acid was made to run upon the carbonate of ammonia, while the clean end of the tube was immersed in a freezing mixture. The gas evolved condensed in the part of the tube surrounded by the freezing mixture. Liquid carbonic acid is colourless, very fluid, and light. Its refractive power is less than that of water. At 32° its elasticity is equal to the pressure of 36 atmospheres.*

This gas undergoes no alteration when passed through a red hot porcelain tube. But when electric sparks are passed through a portion of it standing over mercury, it is decomposed at least partially, and converted into carbonic oxide and oxygen gases. Dr. Henry found that when the undecomposed carbonic acid is withdrawn by means of a solution of potash, an electric spark passed through the residue causes combustion, and converts the whole into carbonic acid gas.† It is obvious from this that it would be impossible, by means of the electric spark, to decompose the whole of any given quantity of carbonic acid into carbonic oxide and oxygen.

If we mix equal volumes of hydrogen and carbonic acid gases, and pass them slowly through a porcelain tube filled with fragments of porcelain, and in a state of ignition, the carbonic acid is converted into carbonic oxide, and the hydrogen into water. The volume of carbonic oxide is precisely equal to that of the carbonic acid.

* Phil. Trans. 1823, p. 189.   † Ibid. 1809, p. 448.

If instead of fragments of porcelain, we fill the tube with pieces of charcoal, and after heating them to redness, pass carbonic acid very slowly through them, it will be converted into carbonic oxide, while at the same time its bulk is doubled. None of the supporters of combustion has any sensible action on carbonic acid, even at a red heat. The same remark applies to azotic gas.

It has been already observed that Lavoisier first proved that carbonic acid is a compound of carbon and oxygen. As the volume of oxygen gas is not altered by burning pure carbon in it, while at the same time it is converted into carbonic acid, it is obvious that the weight of carbon which converts a volume of oxygen gas into carbonic acid gas, may be obtained by subtracting the specific gravity of oxygen gas, from that of carbonic acid gas.

Sp. gr. of carbonic acid gas . .	1·5277
———— oxygen gas . .	1·1111
Weight of carbon . .	0·4166

Hence carbonic acid is composed of

Oxygen	. .	1·1111	or 2
Carbon	. .	0·4166	or 0·75

It is obvious that either 0·75 or a multiple or submultiple of that number exhibits the atomic weight of carbon. Of this we will be better able to judge after we have made ourselves acquainted with the properties and composition of *carbonic oxide*, which is the other compound of carbon and oxygen.

It has been known since the time of Dr. Black, that carbonic acid gas exists in the atmosphere. The older pneumatic chemists concluded from very imperfect data, that the atmosphere contained about $\frac{1}{100}$th of its volume of this gas. Mr. Dalton was the first person who attempted to determine the point by accurate experiments. He found that 10,000 volumes of air contained 6·8 volumes of carbonic acid gas; but that the volume varies at different times. Thenard found 3·91 volumes of this gas in 10,000 of air. But the most complete set of experiments was made by M. de Saussure. He continued them for three years, and tried the quantity of air at Chombeisy, a meadow about three-fourths of a league from Geneva; on the lake of Geneva, in the town of Geneva, and upon the neighbouring mountains of Jura and the Alps. The following are the results which he obtained.

The mean volume of carbonic acid gas in 10,000 volumes of air at Chambeisy, deduced from 104 observations, amounts to 4·15 volumes. The greatest quantity observed was 5·74 volumes, and the smallest 3·15 volumes.

The quantity is diminished by rain, or when the earth is soaked with moisture: doubtless because the moisture absorbs the gas. Thus in July, 1827, the fall of rain was 0·354 inch, and the carbonic acid in 10,000 air was 5·18 volumes.

				Carbonic acid.
In July,	1828,	Rain 6·8	inches . .	4·56 volumes.
	1829,	Rain 2·05	. .	4·32
In Aug.	1827,	2·95	. .	5·01
	1828,	5·04	. .	4·28
	1829,	4·57	. .	3·8

The air over the lake of Geneva contains in general less carbonic acid gas than the air over the land at Chambeisy. But air taken up in a court in Geneva, contains rather more carbonic acid than the air at Chambeisy. The air on the mountains is rather more charged with carbonic acid, than the air over plains. Finally, the air during the night is rather more charged with this gas than during the day, and in winter than in summer, and in windy weather than in calm weather.* •

2. Carbonic oxide gas was discovered by Dr. Priestley about the beginning of the present century, by exposing to a red heat a mixture of charcoal and oxide of zinc. It was first subjected to analysis, and its composition determined by Mr. Cruikshanks. Soon after an elaborate set of experiments on it was published by Clement and Desormes, from which they deduced its constituents to be only carbon and oxygen. But Berthollet soon after subjected it to new experiments, and endeavoured to prove that it was a compound of oxygen, carbon, and hydrogen. Subsequent investigation has shown, in the most satisfactory manner, that it contains no hydrogen, but is a compound of carbon and oxygen.

It may be obtained by various processes, some of which I shall state. 1. When we heat a mixture of oxide of zinc and charcoal, or finery cinder and charcoal, in an iron bottle to redness, carbonic oxide gas is evolved. But this process does not yield it in a state of purity. 2. If we mix three parts of carbonate of lime, or carbonate of barytes, or carbonate of strontian, with one part of well burnt charcoal, and heat the

2. Carbonic oxide.

How procured.

* Saussure, Ann. de Chim. et de Phys. xliv. 5.

mixture in an iron bottle, carbonic oxide gas comes over in abundance, and the earths remain behind in a caustic state. 3. If we mix about equal weights of clean iron filings and carbonate of lime, strontian, and barytes, and heat the mixture pretty strongly, we obtain very pure carbonic oxide, mixed, however, with a good deal of carbonic acid gas, which is easily removed by washing the gas with milk of lime. 4. If we put into a small retort or gas bottle, a mixture of 5 parts of concentrated sulphuric acid and one part of *binoxalate of potash* or *salt of sorrel*, and apply heat to the mixture, a gas is evolved, composed of equal volumes of carbonic acid and carbonic oxide. Caustic potash or milk of lime will remove the carbonic acid, and leave the carbonic oxide in a state of purity. For this last process we are indebted to Dobereiner* and Dumas,† for the others to Dr. Priestley and Mr. Cruikshanks. We may obtain this gas also by passing carbonic acid through red hot charcoal. By this process the carbonic acid gas is doubled in volume, and converted into carbonic oxide.

Properties.   This gas is colourless like common air, and destitute of taste and smell.

I found the specific gravity of this gas 0·970.‡ Berzelius and Dulong found it 0·9727. We shall see immediately that the true specific gravity is 0·9722, which is precisely that of azotic gas.

Its refractive power is 1·157, that of air being 1, according to the experiments of Dulong.§

It produces no change on vegetable blues, does not seem capable of uniting either with acids or bases, and is, therefore, a neutral substance. It has not been condensed into a liquid by the application of cold and pressure.

It is not sensibly absorbed by water; according to Davy, water freed from air by boiling, absorbs $\frac{1}{30}$th of its volume, according to Dalton $\frac{1}{27}$th of volume, according to Saussure $\frac{1}{16}$th of its volume of this gas. My own experiments came nearest those of Davy.

No animal can breathe it; when the attempt is made, one or two inhalations occasion asphyxia. All gases containing carbon have been found positively injurious when drawn into the lungs.

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* Ann. de Chim. et de Phys. xix. 83.   † Ibid. xxxiii. 110.
‡ Annals of Philosophy, xvi. 248.
§ Ann. de Chim. et de Phys. xxxi. 166.

It burns with a beautiful blue flame, and gives out but little light. When mixed with common air it does not explode like hydrogen, but burns brilliantly. However, a mixture of 2 volumes of this gas and 1 volume of air explodes (though not strongly) by an electric spark, or when placed in contact with a red hot wire. It explodes with oxygen gas, and 1 volume of carbonic oxide gas requires, for complete combustion, half a volume of oxygen gas. When such a mixture is exploded over mercury, the residue is exactly 1 volume of carbonic acid gas. Thus it appears that 1 volume carbonic oxide gas $+ \frac{1}{2}$ a volume of oxygen gas, constitute one volume of carbonic acid gas. But we have seen that carbonic acid gas contains its own volume of oxygen gas. It is clear from this that 1 volume of carbonic oxide gas contains just as much carbon as 1 volume of carbonic acid gas. But that the volume of oxygen gas in it is only half as much as in carbonic acid gas. It must therefore be a compound of

Oxygen	0·5555 or 1
Carbon	0·4166 0·75

But carbonic acid is a compound of

Oxygen	2
Carbon	0·75

If, therefore, we consider 0·75 to represent an atom of carbon, it is evident that carbonic oxide will be a compound of 1 atom carbon $+$ 1 atom oxygen, and carbonic acid of 1 atom carbon $+$ 2 atoms oxygen. And the atomic weights of these two bodies will be as follows.

Carbonic oxide	1·75
Carbonic acid	2·75

Carbonic acid gas is a compound of 1 volume carbon vapour $+$ 1 volume oxygen gas, condensed into 1 volume.

1 volume carbon vapour . .	0·4166
1 volume oxygen gas . .	·1·1111
	————
	1·5277 = sp. gravity

of carbonic acid gas.

Carbonic oxide gas is composed of 1 volume carbon vapour $+ \frac{1}{2}$ volume oxygen gas condensed into 1 volume.

1 volume carbon vapour . .	0·4166
$\frac{1}{2}$ volume oxygen gas . .	0·5555
	————
	·9722 = sp. gravity

of carbonic oxide gas.   This must be the true specific gravity of carbonic oxide gas.   It comes within less than $\frac{1}{1000}$th part of the experimental result of Berzelius' and Dulong.

When a mixture of carbonic oxide gas and oxygen gas in 'the proper proportions is exposed to the action of spongy platinum, no action takes place at the common temperature, but when the temperature of the gas is raised rather above 300° it begins to be converted into carbonic acid, and at a temperature rather above 320° it is wholly acidified in the course of a few minutes.   When carbonic oxide gas is added in equal volumes to a mixture of hydrogen and oxygen in explosive proportion, it prevents the spongy platinum from causing detonation; but the action of the gases on each other goes on slowly, and both water and carbonic acid are formed.   But if the quantity of carbonic oxide gas added be small, explosion takes place on introducing the spongy platinum.*

If we mix equal volumes of carbonic oxide and hydrogen gas, and pass the mixture through a red hot tube, the gas is decomposed, charcoal deposited, and water formed.   The gas is decomposed also by potassium which unites to its oxygen. Döbereiner assures us, that by bringing it in contact with sulphuretted oxide of platinum, it is converted into half its volume of carbonic acid.

3. It was discovered by Dr. John Davy that carbonic oxide gas has the property of combining with chlorine.   He gave the compound the name of *phosgene* gas.   But a more systematic name will be *chloro-carbonic acid.*†   The method of procuring it is as follows.

Chloro-carbonic acid.

Into a glass flask, previously exhausted of air and well dried, introduce equal volumes of carbonic oxide and chlorine gases, both well dried by being left in contact with fused *chloride of calcium.*   Expose this mixture to sunshine for about a quarter of an hour.   The colour of the chlorine disappears, and the volume of the mixture diminishes one half.   The new gas, thus formed, is chloro-carbonic acid.

Properties.

It is colourless, and possesses the mechanical properties of common air.   It has a strong smell, which has been compared to what would be produced by a mixture of the odours of chlorine and ammonia.   It is more disagreeable and suffocating

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* Henry; Phil. Trans. 1824, p. 271.
† Berzelius calls it *carbonic oxy-chloride*; Dumas, *chloride of oxide of carbon* or *chloro-carbonic acid*; and Dulong, *oxy-chloro-carbonic acid.*

than that of chlorine, and affects the eyes in a peculiar manner, producing a rapid flow of tears, and occasioning painful sensations. It possesses the properties of an acid, reddening vegetable blues, and combining with, and neutralizing, four times its volume of ammoniacal gas. When tin, zinc, antimony, or arsenic, are heated in this gas, they decompose it, absorbing the chlorine and setting at liberty the carbonic oxide. Water decomposes it, and converts it into muriatic acid and carbonic acid.

Its refracting power, according to Dulong, is 3·936, that of air being 1.*

As it is composed of equal volumes of chlorine and carbonic oxide, condensed into one volume, it is obvious that its specific gravity is equal to that of chlorine gas and carbonic oxide gas united together, or 3·4722.

Alcohol absorbs about 12 times its volume of this gas, does not decompose it, but acquires the smell and the taste which distinguishes the gas. The chloride of arsenic absorbs 10 times its volume of the gas, and the chloride of sulphur also absorbs it; though it has been hitherto impossible to determine the degree of absorption.

This gas neither detonates with oxygen nor with hydrogen gases. But if we mix it with oxygen and hydrogen at once, and pass an electric spark through the mixture, it is converted into carbonic acid and muriatic acid.

The constituents of this gas being one volume of chlorine Composition. gas and one volume of carbonic oxide gas, it is clear that it consists of

1 atom chlorine	.	.	.	4·5
1 atom oxygen	.	.	.	1·0
1 atom carbon	.	.	.	0·75
				————
				6·25

Thus its atomic weight is 6·25, and it is a compound of 1 atom carbon with 1 atom of chlorine and of oxygen. It resembles carbonic acid with this difference, that for one of the atoms of oxygen an atom of chlorine has been substituted.

The salt which it forms with ammoniacal gas is white, neutral, volatile, having a sharp taste and deliquescing in the air. This salt when dissolved in the concentrated mineral acids, gives out muriatic and carbonic acids. But acetic acid dissolves it without effervescence. It is obviously a compound of

* Ann. de Chim. et de Phys. xxxi. 166.

Atomic weight.

1 atom chloro-carbonic acid	.	.	.	6·25
2 atoms ammonia	.	.	.	4·25
				10·5

4. Oxalic acid.

4. *Oxalic acid.* There is another combination of carbon and oxygen, which possesses very powerful acid properties, and which has received the name of *oxalic acid.* It was discovered by Scheele; but first made known to chemists by Bergman. The original mode of preparing it, was to dissolve sugar in nitric acid, and to digest the solution till it ceases to effervesce. On cooling the liquid, crystals of oxalic acid are deposited. But it has been known for some time, that if shavings of wood be mixed with caustic potash, and exposed to a heat considerably higher than that of boiling water, the wood suffers decomposition, and is partly converted into oxalic acid, which combines with the potash. I have reason to believe that this is the process that has been followed for a good many years by the manufacturers of oxalic acid in this country; and it accounts for the low price at which it is sold. The properties of this important acid will be described in a subsequent part of this work. It has been ascertained, that when heated with strong sulphuric acid, it is decomposed and completely converted into carbonic acid, and carbonic oxide, in equal volumes.

Composition. We see, from this, that it is composed of a volume of carbonic acid and a volume of carbonic oxide united together.

Atomic weight of carbonic acid	.	.	2·75
———————— carbonic oxide	.	.	1·75
			4·5

Hence, we see, that its atomic weight is 4·5. Now, 4·5 turns out to be its true atomic weight, when we analyze the oxalates. The constituents of

		Oxygen.	Carbon.
Carbonic acid are	.	2 atoms +	1 atom
Carbonic oxide	.	1 +	1
		3	2

Hence, it follows, that oxalic acid is a compound of 3 atoms oxygen, and 2 atoms carbon.

Forms three compounds with chlorine. II. It was long supposed that carbon and chlorine were incapable of uniting; but Mr. Faraday ascertained, in the year 1821, that the two substances could be united in two different

proportions; and a third compound was soon after discovered by him and Mr. R. Philips. These three compounds may be distinguished by the names of *sesquichloride of carbon, chloride of carbon,* and *dichloride of carbon;* indicating, by these names, the proportions in which the constituents unite.

1. *Sesquichloride of carbon.* It has been long known, that when charcoal is left in contact with chlorine gas, or when it is heated in contact with that gas, no combination whatever takes place. Mr. Faraday succeeded in forming a compound, by means of a gas, known by the name of *olefiant gas.** It was known already that this gas has the property of uniting with its own volume of chlorine gas, and condensing with it into an aromatic and colourless liquid.

Mr. Faraday filled a glass globe, capable of holding 200 cubic inches, with chlorine gas; it was then placed over olefiant gas, and as much as could enter having passed in, the stop-cocks were shut, and the whole left for a short time. The liquid compound of chlorine and olefiant gas formed, and occasioned a partial vacuum. More olefiant gas was then introduced, and this process was repeated, till all the chlorine had combined with olefiant gas, and been converted into a liquid, and the glass was filled with olefiant gas. Then chlorine gas was admitted, till all the olefiant gas had been converted into a liquid, and till the glass vessel was filled with chlorine gas. It was now exposed to the light of the sun. The chlorine gas immediately disappeared, and the vessel became filled with muriatic acid gas. A little water being let in, this gas was absorbed, and the vessel again filled with chlorine gas. Being again exposed to the light, it disappeared as before, and the muriatic acid gas being absorbed, left space for more chlorine. These processes being repeated, the liquid gradually became thick, and white crystals appeared in it. These crystals con-stitute a *sesquichloride of carbon.*

To purify it, the gases were blown out of the glass vessel by a pair of bellows, and water was poured in to wash away the muriatic acid. Now, wash out the crystals, by means of water, into a jar. A little alcohol will wash out what adheres to the vessel, and the alcoholic solution being poured into the water, the sesquichloride will fall to the bottom. Collect the

* This gas will be described in a subsequent part of this section. It is obtained by heating a mixture of alcohol and sulphuric acid. A volume of it contains 2 volumes of hydrogen gas, and 2 volumes of carbon vapour, united together, and condensed into 1 volume.

whole sesquichloride on a filter, and dry it between folds of bibulous paper. Put it now into a glass tube, and sublime it by a spirit lamp. The sublimed portion is then to be dissolved in alcohol, and poured into a weak solution of potash, by which the muriatic acid, which it may contain, is neutralized and separated, while the sesquichloride falls down. Decant off the liquid; wash the sesquichloride clean; dry it first on blotting paper, and afterwards, by placing it in a vacuum, over sulphuric acid. It is now a white powder, and, if pure, may be sublimed, without leaving any charry residue, or liberating any muriatic acid. When dissolved in ether, it will not occasion any precipitate with nitrate of silver.

The direct rays of the sun are not necessary for its formation; the light of day is sufficient; though the process is slower; but lamp-light is not sufficient.

Sesquichloride of carbon is a transparent colourless substance, with scarcely any taste; but having an aromatic odour, approaching to that of camphor. Its specific gravity is 2. Its refractive power high; being above that of flint glass, (1·5767.) It is very friable, easily breaking down under pressure; and when scratched, has much the feel and appearance of white sugar. It does not conduct electricity.

The crystals are usually flat, six-sided prisms terminated by elongated hexagons. Mr. Brooke supposes the primary form to be a right rhombic prism, whose faces make angles with each other of 122° and 78°; but he could discover no cleavage to confirm this opinion.* Mr. Faraday, on the contrary, considers the primary form to be an octahedron.

It volatilizes slowly at common temperatures, and passes, like camphor, to the light. If warmed, it rises more rapidly, and then forms fine crystals. It fuses at 320°, and boils at 360°, under atmospheric pressure. When condensed from these rapid sublimations, it concretes in the upper part of the vessel, in so transparent and colourless a state, as to be hardly perceptible. As the crust becomes thicker, it splits and cracks like sublimed camphor; and, in a few minutes after it is cold, it is white, and nearly opaque.

It is not readily combustible: when held in the flame of a spirit lamp, it burns with a red flame, emitting much smoke and acid fumes. When heated in an atmosphere of oxygen, it burns with a brilliant light.

* Annals of Philosophy (2d series), vii. 364.

It is not soluble in water, whether hot or cold; or only soluble in very minute quantity. In alcohol, it dissolves with facility, and in much greater quantity in hot than in cold alcohol. A saturated hot solution crystallizes as it cools. The alcoholic solution, when mixed with water, lets the ses-quichloride fall in flakes. It is much more soluble in ether than in alcohol, and more so in hot than in cold ether. The hot solution crystallizes as it cools; and the crystallization of a cold solution, when evaporated on a glass plate, is very beautiful. The ether solution is not precipitated by water. It is soluble in volatile oils, and, on evaporation, is again obtained in crystals. It dissolves also in fixed oils. The solution, when heated, lets go muriatic acid gas, and the liquid becomes dark coloured.

Solutions of acids and alkalies act on it with little energy; showing that it is a neutral substance. Caustic potash, soda, and ammonia, do not decompose it. Muriatic acid does not act upon it at all. Strong nitric acid boiled upon it dissolves a portion. Part of this is deposited as the solution cools, and the rest falls when the acid is diluted with water. It is not acted on by sulphuric acid.

It is not acted on by oxygen at temperatures under a red heat. A mixture of oxygen gas, and the vapour of sesqui-chloride of carbon, did not inflame by the electric spark, though raised previously to the heat of 400°; but passed through a red hot tube, it was decomposed, and mixtures of chlorine, carbonic oxide, carbonic acid, and chloro-carbonic acid, produced. A portion of the sesquichloride was heated with the red oxide of mercury, in a glass tube, over mercury. As soon as the heat had risen so high as to soften the glass considerably, the vapour suddenly detonated with the oxygen evolved, with bright inflammation. The substances remaining, were oxygen, carbonic acid, and calomel.

Chlorine does not act on this substance, whether cold or hot. Iodine, at low temperatures, melts with it; and there is no farther action. When heated more strongly in its vapour, the iodine separates chlorine, and reduces the sesquichloride to simple chloride of carbon, while chloriodic acid is produced.

Hydrogen, and the vapour of sesquichloride, do not inflame at 400°, by electricity; but when the mixture is sent through a red hot tube, the whole is decomposed, and muriatic acid gas formed, and charcoal precipitated.

It detonates when its vapour is mixed at once with oxygen

and hydrogen gases, and an electric spark passed through the mixture. But Mr. Faraday could not, in this way, determine its composition.

It readily melts with sulphur, and the mixture crystallizes, on cooling, into a yellowish mass. By a stronger heat, it may be sublimed, leaving the sulphur unaltered; but when the mixed vapours are raised to a still higher temperature, chloride of sulphur, and chloride of carbon, are formed. With phosphorus, it melts and unites at a low temperature, without decomposition. When phosphorus is heated in the vapour of the substance, chloride of phosphorus, and chloride of carbon, are formed. If the phosphorus be heated more highly, it frequently inflames in the vapour with a brilliant combustion, and abundance of charcoal is deposited. Charcoal heated in the vapour of the sesquichloride, exerts no action on it.

Most of the metals decompose it at a high temperature. Potassium burns brilliantly in the vapour; charcoal is deposited; and chloride of potassium formed. Iron, zinc, tin, copper, and mercury, act on it at a red heat; charcoal being deposited, and chlorides formed. When heated with metallic oxides, different results are obtained, according to the oxides. Peroxides of mercury, copper, lead, and tin, produce chlorides and carbonic acid. Protoxides of zinc, lead, &c. produce also chlorides; but the gaseous products are mixtures of carbonic acid, and carbonic oxide. When the vapour of the sesquichloride is passed over red hot lime, barytes, or strontian, a vivid combustion is produced. Chlorides are produced; carbonic acid is formed; and carbon deposited. On magnesia there is no action.

Composition. Mr. Faraday did not succeed in his attempts to analyze this compound directly; but from the phenomena attending its formation, there can be no doubt about the proportions and nature of the constituents. It appears, from his experiments, that, in order to form the sesquichloride of carbon, we must mix together 1 volume of olefiant gas, and 5 volumes of chlorine gas. There are formed 4 volumes of muriatic acid gas.

Now, 4 volumes of muriatic acid gas, are composed of

2 volumes hydrogen gas,
2 volumes chlorine gas.

Thus all the hydrogen in the olefiant gas is converted into muriatic acid. There remain 2 volumes of carbon vapour, which, by uniting with 3 volumes of chlorine, have been condensed into the sesquichloride. From this it is clear, that

sesquichloride of carbon is composed of 1 volume carbon vapour, and 1½ volume chlorine gas, or by weight of.

Carbon	.	0·4166 or 0·75
Chlorine	.	3·75 6·75

But 0·75 is the weight of an atom of carbon, and 6·75 is equal to an atom and a half of chlorine. Sesquichloride of carbon then is composed of

1½ atom chlorine	.	6·75
1 atom carbon	.	0·75
		———
		7·50

and its atomic weight will be 7·5.[*]

2. *Chloride of carbon.* When the vapour of sesquichloride of carbon is heated to dull redness, chlorine is disengaged, and a liquid substance formed, which obviously contains less chlorine than the sesquichloride. This decomposition is not easily effected. Mr. Faraday's process was as follows. A long tube shut at one end was employed : the sesquichloride was put into the bottom of the tube, and the space above it for about twelve inches was filled with fragments of rock crystal. The part of the tube beyond this was then bent up and down two or three times, that the angles might serve for receivers of the new compound.[†] The tube and rock crystal were then heated to bright redness, while the angles were dipt in water. The sesquichloride was then slowly sublimed by a spirit lamp, and decomposed as it passed through the red-hot rock crystal. A fluid passes over, which condenses in the angles of the tube, and some chlorine escapes; but the greatest part is retained in the liquid, and colours it yellow. By the careful application of a lamp and blow-pipe, the bent part of the tube is now to be separated from the portion within the furnace, and its end closed so as to form a small retort. By distilling the fluid four or five times from one angle to another, all the chlorine is driven off, and the liquid becomes limpid and colourless. But it still retains a little sesquichloride. Mr. Faraday's method of getting rid of this, was to heat the fluid till the tube was nearly full of its vapour. The open end of the tube was then hermetically sealed. On cooling, the whole liquid collected at one end of the tube. This end was introduced through a

Chloride of carbon.

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[*] See Phil. Trans. 1821, p. 49. All the facts stated in the text were determined by Faraday, and will be found in the paper here quoted.

[†] Mr. Faraday has given a description of these bent tubes, in his Chemical Manipulation, p. 400.

cork into a receiver, under which a small flame was burning. By this means the liquid was distilled by a very gentle heat into the cold part of the tube, while the sesquichloride remained behind.

Properties.   Chloride of carbon is a highly limpid fluid perfectly colourless. Its specific gravity is 1·5526. Its refracting power, as determined by Dr. Wollaston, is 1·4875, being very nearly that of camphor. It is not combustible, except when held in a flame. It then burns with bright yellow light, much smoke, and exhales fumes of muriatic acid.

It does not congeal at zero. When its temperature is raised to between 160° and 170°, it is converted into vapour, and remains in that state till the temperature is lowered. At a red heat it undergoes a partial decomposition, becoming slightly coloured, and the tube being blackened by charcoal.

It is not soluble in water; but it dissolves in alcohol and ether, and the solutions burn with a greenish flame, giving out fumes of muriatic acid. It dissolves also in the volatile and fixed oils. It is not acted on by alkaline solutions, nor by nitric, muriatic, nor sulphuric acids. Solutions of silver do not act upon it.

Oxygen decomposes it at high temperatures, forming carbonic oxide or acid, and liberating chlorine. Chlorine dissolves it in considerable quantity, but has no further action, or only a very slow one, in common daylight. But when exposed to the direct light of the sun it is converted into sesquichloride of carbon. It dissolves in iodine very readily, and forms a brilliant red solution. It does not detonate with hydrogen when in the state of vapour. But when electric sparks are passed through such a mixture, the chloride is gradually decomposed and muriatic acid formed. When such a mixture is passed through a red-hot tube, the chloride is completely decomposed, muriatic acid formed, and charcoal deposited. When the vapour is mixed with oxygen and hydrogen it detonates by electricity, and a complete decomposition is produced.

Sulphur and phosphorus dissolve it, but do not decompose it at low temperatures. Phosphorus decomposes it at a red heat. Its action on metals and metallic oxides is very similar to that of sesquichloride.

To determine the composition of this chloride Mr. Faraday passed 2·7 grains of it over red-hot barytes. A brilliant combustion was produced, carbonic acid being evolved, and char-

coal deposited. When the tube was cold the barytes was dissolved in nitric acid, and the chlorine precipitated by nitrate of silver. The chloride of silver weighed 9·4 grains = 2·318 gr. of chlorine. Hence 3 gr. would have given 2·575 gr. chlorine.

Three grains of the chloride were passed through red-hot black oxide of copper in an iron tube. 3·5 cubic inches of carbonic acid gas were obtained. Now 3·5 cubic inches of carbonic acid gas weigh 1·66 grains, which contains 0·453 grain of carbon.

Thus it appears that chloride of carbon is composed of

Composition.

Chlorine	. .	2·575 or 4·5
Carbon	. .	0·453 or 0·79

Now 4·5 represents an atom of chlorine, and 0·79 approaches pretty nearly an atom of carbon.

The analysis, though not absolutely exact, is sufficiently so to leave no doubt that chloride of carbon is a compound of

1 atom chlorine	. .	4·5
1 atom carbon	. .	0·75
		———
		5·25

Hence its atomic weight is 5·25. Like sesquichloride of carbon this compound is a neutral body, and shows no tendency to combine either with acids or alkalies.

3. *Dichloride of carbon.* Mr. Julin of Abo was proprietor of a manufactory in which nitric acid was prepared by distilling calcined sulphate of iron with crude nitre, in iron retorts, and the product was collected in receivers connected with glass tubes, after the manner of Wolfe's bottles. When he employed a peculiar kind of calcined vitriol from Fahlun, known in Sweden by the name of calcined aqua fortis No. 3, the first tube was lined with sulphur, and the second with fine white feathery crystals. These amounted only to a few grains each distillation. But M. Julin by degrees collected a portion of it. An account of it was inserted in the Annals of Philosophy during the year 1821.* It was subjected to a chemical examination during the same year, by Messrs. Faraday and R. Philips, who showed it to be a compound of 1 atom chlorine and two atoms carbon.† These acicular crystals when purified by subliming them through lime are of a beautiful white colour. The

Dichloride of carbon.

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* Vol. i. p. 216 (second series).
† Phil. Trans. 1821, p. 392.

shape of the crystals appeared to Mr. W. Philips to be a four-sided prism.

It sinks slowly in water, is tasteless, and has a peculiar smell, which Mr. Julin compares to that of spermaceti. It is insoluble in water, and is not acted on by sulphuric, nitric, or muriatic acids. Nor is it acted on by alkaline solutions. It dissolves in alcohol, and, doubtless, also in ether, though the action of that liquid was not tried. It is soluble in hot oil of turpentine, and is deposited in needles as the liquid cools.

When heated it melts, and boils and sublimes at a temperature between 350° and 400°. At 250° it sublimes slowly without melting. In the flame of a lamp it burns with a greenish blue flame, giving a slight smell of chlorine gas. Potassium burns vividly in its vapour, and carbon is deposited. The burnt potassium being dissolved in water, was copiously precipitated by nitrate of silver.

When passed through fragments of rock crystal, heated to a bright red, it was decomposed, charcoal being deposited, and chlorine disengaged. It was not acted on by chlorine. When the vapour was mixed with oxygen gas, and detonated over hot mercury, carbonic acid gas and chloride of mercury were formed. There was no change of volume when the oxygen was in excess; but when the vapour was in excess the volume increased after the explosion, and carbonic oxide, carbonic acid, and chloride of mercury were formed. Phosphorus, iron, tin, &c. when heated to redness in its vapour, decomposed it; chlorides of these bodies being formed, and charcoal deposited.

Three grains of it passed in vapour through red-hot black oxide of copper, gave 5·7 cubic inches of carbonic acid, and the chlorine in the oxide of copper being thrown down, gave 6·1 grains of chloride of silver. In this experiment the whole of the substance was not decomposed.

. 5·7 cubic inches of carbonic acid gas weigh 2·7 grains, and contain 0·736 grain of carbon.

6·1 grains of chloride of silver contain 1·5 gr. of chlorine. This gives us

Chlorine	.	.	1·5　or 4·5 or 1 atom
Carbon	.	.	0·736　2·2 or 3 atoms

Two grains were passed over quicklime, raised to a red heat in a green glass tube. Ignition took place, and much charcoal was deposited. The lime being dissolved in nitric acid, and the solution precipitated by nitrate of silver, 5·9 grains of

chloride of silver were obtained = 1·45 chlorine. According to this experiment it is composed of

Chlorine	. . .	1·45 or	4·5 or	1 atom
Carbon	. .	0·55	1·7	$2\frac{1}{373}$ atom
		2·00		

This last experiment is much more accurate than the preceding, and it comes so near 1 atom chlorine and two atoms carbon, that we can have little hesitation in considering the substance discovered by M. Julin, to be a dichloride of carbon, or a compound of

1 atom chlorine	. .	4·5
2 atoms carbon	. .	1·5
		6

So that its atomic weight is 6. Like the other two compounds of chlorine and carbon it is a neutral body.

III. Serullas has discovered a liquid compound of bromine and carbon which has not yet been subjected to a rigid analysis; but from analogy there can be little doubt that it is a simple bromide of carbon like the chloride of Faraday.

Sesquiodide of carbon was thrown upon bromine in excess, in a glass tube. The action was instantaneous; much heat was evolved, and a noise was heard similar to that which takes place when a red-hot iron is plunged into water; bromide of iodine and bromide of carbon are formed at once. Water dissolves the bromide of iodine, while the bromide of carbon remains in the state of a liquid at the bottom of the water, and coloured by an excess of bromine. This is removed by caustic potash. The bromide of carbon thus purified is a colourless liquid. It has an etherial and penetrating smell, and an exceedingly sweet taste, which it communicates to water, being slightly soluble in that liquid.*

By exposure to the air it acquires a light red colour. It is heavier than water, but its exact specific gravity has not been ascertained. When cooled down to about 45° it becomes solid, assuming a crystalline texture. When heated at the flame of a candle, it gives out the red vapours of bromine; but does not burn with flame.† This bromide has not been analyzed; but analogy leaves little doubt that it is a simple bromide composed of

* Ann. de Chim. et de Phys. xxxiv. 97.   † Ibid. xxxix. 228.

1 atom bromine	.	.	10
1 atom carbon	.	.	0·75
			10·75

So that its atomic weight is 10·75

When an alcoholic solution of bromine is mixed with an alcoholic solution of potash, the mixture acquires a sweet taste and an aromatic smell; showing the formation of bromide of carbon. But no sesquibromide of carbon can be obtained in this way, as happens with the analogous solutions of iodine.*

Hydro-carbu-
ret of bro-
mine.
2. Balard ascertained that bromine readily combines with carbon and hydrogen, or rather with olefiant gas, forming a compound, which has been called *hydro-carburet of bromine.*

If we let a drop of bromine fall into a phial filled with olefiant gas, it is immediately converted into a transparent colourless liquid, having no more the odour of bromine; but an aromatic and agreeable smell. It is readily volatilized, and when passed through a red-hot tube it undergoes decomposition; charcoal is deposited and hydrobromic acid disengaged.

It burns when placed in contact with a red-hot body, giving out acid vapours and a thick smoke consisting of carbon in a minutely divided state.

We obtain a similar compound by distilling the mother water of salt springs, rendered yellow by chlorine. The bromine obtained is often mixed with hydro-carburet of bromine, which may be separated by a little water. Sometimes in performing this operation, the whole bromine is converted into this hydro-carburet. The change is probably owing to the action of the bromine on some *organic* matter contained in the water.†

Iodides.
IV. It appears from the experiments of Mitcherlich, that carbon and iodine unite in two proportions, as well as carbon and chlorine, forming a solid and a liquid compound, which have considerable resemblance to the analogous chlorides of carbon.‡ These two compounds were both discovered by Serullas.§

Sesquiodide of
carbon.
1. *Sesquiodide of carbon.* This compound was discovered by Serullas in 1722. Mr. Cooper discovered it in 1723, while engaged in the preparation of iodine, without being aware of

* Ann. de Chim. et de Phys. xxxix. 229.
† Ibid. xxxii. 375.   ‡ Ibid. xxxvii. 85.
§ Ibid. xx. 163   xxii. 172; and xxv. 311.

the previous experiments of Serullas.*   It was again discovered by Mr. Scanlan in 1825.†   Both Mr. Cooper and Mr. Scanlan considered it as a simple iodide of carbon.   Serullas considered it as a compound of iodine, hydrogen, and carbon.   Mr. Faraday, who witnessed the experiments of Mr. Cooper, was not quite convinced that it contained no hydrogen.   Mitcherlich has not yet published his experiments.   But Serullas resumed the investigation,‡ and satisfied himself that it is a true sesquiodide of carbon.   Indeed, the analogy between these compounds and the chlorides is so close, as to leave little doubt of the identity of their composition.

Preparation.

The easiest method of obtaining it is that of Mr. Scanlan. It is this.   To an alcoholic solution of iodine add caustic potash till the colour be destroyed, the liquid becomes turbid, and a white powder, iodate of potash, falls.   Distil with a very gentle heat the alcohol from the clear liquor, which is yellowish.   On cooling, the iodide of carbon is deposited.

Properties.

Iodide of carbon thus obtained is in small plates, opaque, and of a bright sulphur yellow colour.   It has a strong aromatic odour, resembling that of saffron.   Its taste has been compared to that of nitric ether.   I would call it *sweet*, judging from my own palate.   Its specific gravity, as determined by Serullas, is 2, or the same as that of sesquichloride of carbon.

When heated it melts, and if the heat be increased, iodine vapours rise, and carbon remains behind.   It may be distilled over, along with water, unchanged; but a heat not much higher than that of boiling water decomposes it.   At least it may be decomposed by heating it on paper without charring the paper.

It is insoluble in water.   But dissolves readily in alcohol, and when the solution is mixed with water, the iodide falls yellowish white.   When the alcoholic solution is exposed to spontaneous evaporation, the iodide crystallizes in slender prisms.   When heated with iron or zinc it is decomposed, and a metallic iodide formed.

Composition.

Serullas analyzed this compound by passing it through hot black oxide of copper.   One gramme of the sesquiodide gave 0·05824 litres = 3·554 cubic inches of carbonic acid, containing 0·458 grain of carbon.   The copper dissolved in nitric acid, and precipitated by nitrate of silver gave 1·698 grammes

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* Annals of Philosophy (2d series), x. 15.   † Ibid. p. 14.
‡ Ann. de Chim. et de Phys. xxxix. 225.

of iodide of silver, containing 14 grains troy of iodine.   Hence it is composed of

Iodine	.	.	14	or	22·92
Carbon	.	.	0·458	or	0·75

Now 0·75 represents an atom of carbon, and 22·92 differs but little from $1\frac{1}{2}$ atom of iodine.   For $1\frac{1}{2}$ atom iodine = 23·625. From this analysis there seems no doubt that it is a sesquiodide of carbon, and quite analogous to the sesquichloride of carbon discovered by Faraday.*

Iodide of carbon.

2. Iodide of carbon was discovered by Serullas after he had become acquainted with the solid iodide.   His mode of obtaining it was as follows.†   Equal weights of *bichloride of phosphorus*‡ and sesquiodide of carbon, both as dry as possible, are triturated together in a mortar.   This mixture is put into a phial, into the mouth of which a bent tube was luted.   Heat is applied to the bottom of the phial while the open end of the tube is plunged into a vessel filled with water.   The heat must be just sufficient to melt the iodide of carbon.   Some vapours of iodine first make their appearance.   Then a red liquid passes over and falls to the bottom of the water, where it speedily loses its red colour.   Iodine, chloride of iodine, and iodide of phosphorus, remain in the phial.   The liquid is separated from the water, which has become acid, by means of a funnel with a capillary tube.   Then a solution of caustic potash is poured over it to wash it; and this solution is afterwards separated in the same way by means of a funnel.   Care must be taken not to apply too much heat to the phial towards the end of the process; otherwise a portion of the residue passes over, acts upon the liquid iodide of carbon, occasions a considerable heat, and diminishes its quantity considerably.

The liquid thus obtained is iodide of carbon, not however quite free from hydrocarburet of chlorine.   From this it is freed by pouring on it about five times its bulk of concentrated sulphuric acid, and stirring the mixture from time to time with a glass rod.   By the action of this acid the hydrocarburet of chlorine is destroyed, and the pure liquid iodide of carbon collects at the bottom, being heavier than the sulphuric acid.   It is separated by the capillary funnel, washed with a solution of

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* Ann. de Chim. et de Phys. xxxix. 230.   † Ibid. xxv. 314.

‡ A solid volatile substance, obtained by burning phosphorus in chlorine gas.   It will be described in the 6th section of this chapter.   It has been since found much better to substitute corrosive sublimate for this bichloride.

caustic potash, to get rid of the sulphuric acid; and lastly, with
pure water to get rid of the potash.

Iodide of carbon thus prepared is a transparent, light yellow Properties.
liquid, heavier than concentrated sulphuric acid. It has a
peculiar etherial smell, very powerful and agreeable. Its taste
is very sweet, with a sensation of coolness analogous to that
produced by mint. It is slightly soluble in water, to which it
communicates its taste and smell. Chlorine in solution in
water does not act upon it; but gaseous chlorine decomposes it
rapidly. Sulphuric acid does not act on it. It does not become
solid though cooled down to 32°.

When exposed to the air, even under water, and in close
vessels, it assumes a red colour, which becomes more and more
intense. Potassium is not altered by it. It does not burn
though brought in contact with the flame of a candle. But it
gives out abundance of violet-coloured vapours, which act power-
fully on starch jelly, rendering it blue. Oxygen gas mixed
with its vapour, neither burns by electricity, nor when held to
the flame of a candle.

Serullas, after ascertaining that it contained no hydrogen,
(and indeed from the substances employed in its preparation,
there was no room for supposing that it contained any,) sub-
jected it to analysis by passing it through red-hot black oxide
of copper. He collected and measured the carbonic acid gas Composition.
formed, and threw down the iodine in the state of iodide of
silver, by dissolving the copper in nitric acid, and adding nitrate
of silver to the solution. He has not given us the steps of the
analysis, but merely the quantities obtained, which he states
to be

Iodine	.	.	0·9952 or 16·14
Carbon	.	.	0·0462 or 0·75

0·75 is the weight of an atom of carbon, and 16·14 approaches
very nearly 15·75, the weight of an atom of iodine.

There can be no doubt from this analysis that the iodide is
a compound of

1 atom iodine	.	.	15·75
1 atom carbon	.	.	0·75
			16·50

So that its atomic weight is 16·5, and it is quite analogous to
the chloride of carbon discovered by Faraday.*

* Serullas; Ann. de Chim. et de Phys. xxxix. 231.

3. *Hydrocarburet of iodine.* This compound was discovered by Mr. Faraday in 1821. A retort containing iodine was filled with olefiant gas and exposed to the rays of the sun. The gas was gradually absorbed by the iodine, and colourless crystals made their appearance. These crystals constitute the hydrocarburet of iodine. To obtain them pure, a solution of caustic potash was introduced into the retort to wash out the excess of iodine. The hydrocarburet was then collected on a filter and dried.

Properties.

It is a solid white crystalline body, having a sweet taste and aromatic smell. It sinks readily in sulphuric acid of the specific gravity 1·85. It is friable. It is a non-conductor of electricity. When heated it first fuses, and then sublimes unaltered. Its vapour condenses into crystals, which are either prismatic or in plates. On becoming solid, after fusion, it crystallizes in needles. The crystals are transparent. When strongly heated it is decomposed, and iodine evolved. It is not readily combustible, but when held in the flame of a spirit lamp it burns, diminishing the flame, and giving out abundance of iodine and some fumes of hydriodic acid. It is insoluble in water, and in acid and alkaline solutions. It is soluble in alcohol and ether, and may be obtained in crystals from these solutions. The alcoholic solution has a very sweet taste, but leaves a peculiarly sharp biting sensation on the tongue.

Sulphuric acid does not dissolve it. When heated in the acid to between 300° and 400° it is decomposed, apparently by the heat alone; iodine, and a gas (probably olefiant gas), being disengaged. Solution of potash acts on it very slowly, even at the boiling point; but gradually decomposes it.*

Composition.

Mr. Faraday analyzed it by passing 4 grains of it over heated copper in a green glass tube. Iodide of copper was formed, and pure olefiant gas evolved, amounting to 1·37 cubic inches. Now 1·37 cubic inches of olefiant gas weigh 0·415 grain.† Hence the hydrocarburet is composed of

Iodine	. .	3·585 or 15.75
Olefiant gas	. .	0·415 or 1·824

                                 4·000

Now olefiant gas is a compound of two atoms of carbon = 1·5, and 2 atoms of hydrogen = 0·25 ; so that its atom weighs 1·75 ;

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* Phil. Trans. 1821, p. 72.
† Annals of Philosophy (2d series), iv. 153.

And 1·824 exceeds this only a very little. The error arises, doubtless, from the difficulty of estimating the volume of gas evolved with absolute precision. There can be no doubt then, that this hydrocarburet is a compound of

1 atom iodine	. .	15·75
1 atom olefiant gas	. .	1·75
		17·50

And that its atomic weight is 17·5. Like the iodides of carbon, it is a neutral substance, being incapable of forming definite compounds with acids or bases. It differs from the solid iodide of carbon, simply by containing 2 atoms of hydrogen, which that compound wants.

If we could succeed in forming a compound of two atoms of iodine with one atom of carbon, it would probably possess acid properties. It would in its composition be analogous to carbonic acid. The iodides of carbon known, contain a greater proportion of carbon than even carbonic oxide. We need not be surprised then that they are neutral. For carbon, in the simple combinations which it forms with supporters, shows no disposition to constitute a base or alkaline body.

V. Nothing is at present known respecting the combinations of *carbon* and *fluorine.*

VI. Carbon and hydrogen have the property of combining with each other in a great number of proportions, and of forming many compounds, all of which are remarkably combustible, and many of them are of great importance. It would be improper here to give an account of the whole of them, as many of them belong to the vegetable kingdom, and constitute compounds, with the constitution of which we are but imperfectly acquainted. I shall satisfy myself here with pointing out those compounds of hydrogen and carbon that are simplest in their nature, and whose constitution has been most accurately made out. Hydro-carbu-
rets.

1. *Carburetted hydrogen gas.* This gas makes its appearance in coal mines, and has been long known under the name of *fire damp.* Accounts of it, as early as 1640, are recorded in the Philosophical Transactions.* It is mentioned by Dr. Priestley under the name of *heavy inflammable air;* but was not particularly examined by him. It was Mr. Dalton who Carburetted
hydrogen.

* Phil. Trans. 1677, No. 136, p. 895.

first determined its composition with accuracy. I confirmed the accuracy of his results in 1811.

We are not acquainted with any method of forming it artificially; but it may be collected pure, or nearly so, from a *blower* in a coal mine. There is a very copious discharge of it through a small rivulet, which crosses the north road between Glasgow and Edinburgh, about seven miles from Glasgow, and only a few hundred yards from the house of Bedlay. It forms a jet several inches in diameter, and issues with considerable violence, as if it had been in a state of compression under the earth. This gas is pure, except that it is mixed with 12·5 per cent. of common air.

This gas may also be collected from stagnant water pools by attaching a large glass phial to a piece of wood, so that it shall float on the surface of water, with its mouth just under the surface. Into this mouth should be fixed a funnel (a piece of stout oiled paper will answer). Fill the phial with water, and set it afloat with its mouth undermost. Then stir the mud at the bottom of the pond or ditch. Air bubbles rise in abundance, and soon fill the phial. The gas, thus collected, should be washed with a solution of potash, or with lime water, in order to separate a quantity of carbonic acid with which it is mixed. It usually contains, also, some common air. But I shall suppose it pure in the following description.

Properties.   Carburetted hydrogen, thus obtained, is colourless, and possesses the mechanical properties of common air. It has neither taste nor smell. Its specific gravity is 0·5555.

Its power of refracting light is, according to the experiments of Dulong, 1·504, that of air being 1.[†] Perkins affirms that he condensed it into a liquid, by subjecting it to a pressure of 1200 atmospheres.[‡]

It produces no change on vegetable blues, and does not combine either with acids or bases. It is, therefore, a neutral compound.

This gas cannot be breathed by animals without danger. When it is drawn two or three times into the lungs it produces asphyxia. I once accidentally inhaled it; being anxious to empty a gas-holder filled with it, as quickly as possible, I applied my mouth to the stop-cock to draw it out. After two or three

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[*] Memoirs of the Wernerian Society, i. 506.
[†] Ann. de Chim. et de Phys. xxxi· 266.   [‡] Phil. Trans. 1826, p. 544.

inhalations I fell insensible on the floor. But recovered again in about twenty minutes without feeling any bad effects whatever, except a slight headach, which soon went off.

Carburetted hydrogen burns with a strong yellow flame similar to that of a candle when a jet of it is kindled by the application of a burning candle to it. But it requires a much higher temperature to set it on fire, than any other gas whatever. Davy showed that a white heat was requisite for the purpose. Hence the reason why a lamp surrounded with wire gauze does not cause a mixture of this gas and common air to explode in coal mines. This constitutes the lamp of Davy, which has been of so much use in the working of those mines which are troubled by fire-damp. When carburetted hydrogen gas gets within the lamp it burns; but the flame is so much cooled in passing through the meshes of the gauze as to be unable to set fire to the exploding mixture in the mine. It is for the same reason that a mixture of carburetted hydrogen and oxygen gas is not acted on at ordinary temperatures by spongy platinum. Even a temperature of 555° was found by Dr. Henry insufficient to cause any combination. Upon this mixture spongy platinum was quite inert.

When this gas is mixed with oxygen gas, and when an electrical spark is passed through the mixture, it detonates with considerable violence. It does not burn unless the bulk of the oxygen rather exceeds its own bulk; and it ceases to burn when the oxygen is more than $2\frac{1}{4}$ times its own bulk. If we mix it with common air, it burns if it amounts to $\frac{1}{12}$th of the air, and it ceases to burn if it exceeds $\frac{1}{6}$th of the air. In all proportions between these two extremes, it burns with violence. For complete combustion it requires twice its volume of oxygen gas, and produces exactly its own volume of carbonic acid gas. The only remaining product is water. Now it is Composition. obvious that one half of the oxygen went to the formation of carbonic acid, and the other half to the formation of water. This last portion must have combined with a quantity of hydrogen, which, if it had been in an uncombined state, would have amounted to twice the volume of the original gas. Therefore carburetted hydrogen is composed by weight of

1 volume carbon vapour	. .	0·4166 or 0·75
2 volumes hygrogen gas	. .	0·1388 or 0·25

or of three parts of carbon and 1 part of hydrogen. It is obvious that 0·75 represents 1 atom of carbon, and that 0·25

represents two atoms of hydrogen. It is therefore a compound of

1 atom carbon	.	.	0·75
2 atoms hydrogen	.	.	0·25
			1

And its atomic weight is precisely the same as that of oxygen or unity.

When this gas is mixed with chlorine no action takes place in the dark. But when the mixture is exposed to the light, at least if it be in contact with water, the carburetted hydrogen is gradually converted into carbonic acid. That the decomposition may be complete, we must mix together four volumes of chlorine with one volume of carburetted hydrogen gas. The carbonic acid gas formed constitutes a volume. It is obvious that two atoms of water must be decomposed in this process. The 4 volumes of chlorine are converted into muriatic acid. For this they must combine with 4 volumes of hydrogen gas. Two of these volumes exist in the carburetted hydrogen; the other two must be obtained from water. These two volumes of hydrogen will liberate 1 volume of oxygen; which uniting with volume of carbon in the carburetted hydrogen will form a volume of carbonic acid. Such is the process. It was first studied by Mr. Cruikshanks, and afterwards more completely investigated by Dr. Henry.

It is said that this gas is absorbed and destroyed by chloride of lime, and the use of this substance, now so cheap and so easily procured, has been recommended to free coal mines of this most disagreeable inmate, and to render them clear. It is said that if six or eight pounds of chloride of lime be spread over night in a contaminated gallery, the whole carburetted hydrogen will be absorbed in a few hours.* I am not aware of any case in which this trial has been made in this country, but the proposal is surely deserving the attention of coal proprietors, especially near Newcastle, where so many accidents from *fire damp* annually occur.

Oleflant gas.   2. *Olefiant gas.* This gas was discovered in 1796 by the associated Dutch chemists Bondt, Dieman, Van Troostwick, and Lauwerenburg.† Some experiments were afterwards made upon it by Cruikshanks, Berthollet, and Dr. Henry;

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* Dumas' traité de Chimie appliquée aux arts, i. 482.

† Their Memoir was published in the Jour. de Phys. xlv. 178, and an abstract of it in the Ann. de Chim. xxi. 48.

and its composition was accurately investigated by Mr. Dalton. I published a set of experiments on it in 1811.* About the same time an analysis of it was published by M. Theodore de Saussure.†

It is easily obtained by mixing together in a retort four parts of sulphuric acid, and one part of alcohol, and applying the heat of a lamp while the beak of the retort is plunged into a water trough. A gas comes over in abundance, which may be received in glass jars inverted over water.

Olefiant gas, thus prepared, is invisible, and possesses the mechanical properties of common air. It is destitute both of taste and smell. Its specific gravity, as determined by me with great care, is 0·9709. But it will be seen immediately that its true specific gravity is 0·9722, or the same as that of azotic gas. Its refracting power, as determined by Dulong, is 2·302, that of air being 1.‡ No attempts have been made to reduce it to a liquid by pressure. It would certainly require less pressure than carburetted hydrogen gas.

This gas, like all those containing carbon, is not fit for respiration. When drawn into the lungs it produces asphyxia.

It produces no effect on vegetable blue colours. From this it would seem that it is a neutral body. But there are many facts that would lead us to admit that it possesses the characters of a powerful base. For it seems to be capable of combining with, and neutralizing some of the most powerful acids. Mr. Faraday has observed, that sulphuric acid has the property of absorbing about 83 times its bulk of it,‖ and by this its capacity for saturation is diminished. It is believed at present, that nitric ether and some other ethers are combinations of this gas with an acid. We shall find afterwards, that it has the property of combining with sulphuric acid, and of modifying its nature. And some of the compounds which it forms with iodine and bromine have been already noticed. In short, from its characters taken altogether, it must be considered as a base; but a base incapable of producing any alteration on vegetable blues.

When electric sparks are passed through olefiant gas for some time, its volume increases, and carbon is thrown down.

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* Memoirs of the Wernerian Natural History Society, i. 504.
† Ann. de Chim. lxxvii. 57.
‡ Ann. de Chim. et de Phys. xxxi. 266.
‖ In the dull light of a room sulphuric acid absorbs about seven times its volume of this gas.

It is said that by continuing this process the whole carbon may be thrown down, and nothing remains but pure hydrogen gas. In such a case the volume of the gas is just doubled, showing that it contains just twice its volume of hydrogen gas. It is said, also, that it is decomposed into carbon and hydrogen, or carburetted hydrogen, when passed through a red-hot porcelain tube.

This gas burns with greater splendour than any other known gas, and detonates very loudly when mixed with thrice its bulk of oxygen gas, and an electrical spark is passed through it. It requires for its complete combustion three times its volume of oxygen gas, and produces, when burnt, twice its volume of carbonic acid gas. The only other product is water. Now two of the three volumes of oxygen gas must have gone to the formation of carbonic acid. The remaining volume must have

gone to the formation of water, and it must have combined with a quantity of hydrogen, which in an uncombined state would have amounted to two volumes. Hence it is composed of two volumes of carbon and two volumes of hydrogen gas condensed into one volume.

$$2 \text{ volumes hydrogen} = 0 \cdot 1388$$
$$2 \text{ volumes carbon vapour} = 0 \cdot 8333$$
$$\overline{\phantom{2 \text{ volumes carbon vapour} = } 0 \cdot 9722}$$

We see from this that the true specific gravity must be $0 \cdot 9722$. But 2 volumes of hydrogen and 2 volumes of carbon vapour represent each 2 atoms. It follows, therefore, that olefiant gas is a compound of

		Atomic weights.
2 atoms carbon	. .	1·5
2 atoms hydrogen	. .	0·25
		1·75

We see from this that its atomic weight is 1·75; the same with the weight of an atom of azote.

Water, according to the experiments of Mr. Dalton, absorbs one-twelfth of its bulk of olefiant gas.* According to Saussure, 100 cubic inches of water absorb 15·3 cubic inches of olefiant gas.†

When olefiant gas and chlorine gas are placed in contact with each other, a diminution of bulk takes place, and a liquid

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* Phil. Mag. xxiv. 15.   † Annals of Philosophy, vi. 340.

substance is formed which has somewhat the appearance of an oil, when the condensation takes place over water. The formation of this substance was first observed by the Dutch chemists, and it induced them to contrive the term *olefiant gas* for the hydret of carbon. I examined this compound in 1810, and ascertained that it is a compound of olefiant gas and chlorine.* Its properties and composition were still more accurately investigated in 1816, by MM. Robiquet and Colin.†

It is formed by the union of equal volumes of chlorine and olefiant gas. If a current of the two gases from separate vessels meet in a large glass globular vessel, they combine and form the liquid in question, which collects at the bottom of the globe. To render it pure there must be rather an excess of olefiant gas. When there is an excess of chlorine, the liquid absorbs it, acquires a greenish colour and acid properties. But it may be rendered pure by washing it with a little water, and then distilling it off chloride of calcium. It is limpid and colourless like water, has an agreeable smell similar to that of muriatic ether, and a peculiar, sharp, sweetish, agreeable taste. Its specific gravity at 45° is 1.2201, the specific gravity of water being 1. It boils at 152°. At the temperature of 49°, its vapour is capable of supporting a column of mercury 24·66 inches in length. The specific gravity of this vapour has been found 3·4434, that of air being 1. Now the specific gravity of chlorine and olefiant gas, added together, make 3·4722. Hence it is obvious that this body is formed by a volume of chlorine and a volume of olefiant gas, condensed each into half its volume. It is therefore a compound of

<div style="margin-left:2em">

1 atom chlorine   .   .   **4·5**

1 atom olefiant gas   .   .   **1·75**

                            6·25

</div>

And its atomic weight is 6·25. This substance has some analogies to ether, but its solubility in water is much greater than that of ether. We may, therefore, call it *hydro-carburet of chlorine*.

Hydro-carbu-ret of chlo-rine.

This liquid burns with a green flame, giving out copious fumes of muriatic acid and much soot. It is decomposed by being passed through a red-hot porcelain tube, and converted

Properties.

* Memoirs of the Wernerian Society, i. 516.
† Ann. de Chem. et de Phys. i. 337, and ii. 206.

into muriatic acid, and an inflammable gas, containing hydrogen and carbon; while a copious deposite of charcoal is made in the tube. The inflammable gas appears to contain no other constituent but carbon and hydrogen. The liquid is decomposed, likewise, when passed through red-hot oxide of copper. Serullas observed, that this liquid becomes solid when cooled down to 45°.*

Carbo-hydrogen.   3. *Carbo-hydrogen.* Manufactories of acetic acid from wood have existed in this country for a considerable number of years. It is pretty generally known, that during the process there is obtained a transparent spiritous liquor, somewhat more volatile than alcohol. This liquor Messrs. Macaire and Marcet, who analyzed it, have distinguished by the name of *pyroxylic spirit.*† If you mix together in a flask, 3 parts of muriatic acid, 1 part of nitric acid, and 1 part of pyroxylic spirit, and fixing a bent tube to the mouth of the flask, plunge the open end of the tube into a mercurial trough; heat the mixture over a spirit lamp till it begin to effervesce, and till the colour changes to red, then remove the lamp; a violent effervescence takes place, and a prodigious quantity of gas passes over. Allow a sufficient quantity to escape, to be certain that all the air of the flask has been driven out, then collect the gas in inverted jars, filled with mercury.

Sesquichloride of carbo-hydrogen.   The gas thus obtained is mixed with chlorine, which, however, is speedily absorbed by the mercury. When thus freed from chlorine it possesses the following characters.

It is transparent and colourless, and possesses the mechanical properties of air.

Its smell is exceedingly pungent and disagreeable; but so peculiar that I can compare it to nothing else. It acts with considerable energy on the eyes and nose, occasioning a flow of tears, and exciting considerable pain in the eyes.

It is combustible, and burns with a lively bluish white flame.

Water absorbs about five times its volume of it, acquiring a pungent taste, and the peculiar smell of the gas; but it does not alter the colour of litmus or cudbear paper. One volume of oil of turpentine absorbs 30 volumes of this gas. It acquires a green colour like cajeput oil; but still retains its peculiar smell. The gas is neither absorbed by acids nor alkalies.

This gas being analyzed, was found to be a mixture of

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* Ann. de Chim. et de Phys. xxxix. 228.
† It will be described in a subsequent part of this work.

New inflammable gas	.	.	29
Deutoxide of azote	.	.	63
Azotic gas	.	.	8
			100

The specific gravity of the inflammable gas was found to be 4·1757. For complete combustion it required twice its volume of oxygen gas. It was found in repeated trials, that 12 volumes of the gas consumed 24 volumes of oxygen, and that 16 volumes of carbonic acid gas was formed. At the same time water appeared, and a quantity of calomel was formed. For the combustion took place over mercury. It appears from this, that the gas was a compound of carbon, hydrogen, and chlorine. We may leave the chlorine out of view in determining its composition, as the oxygen consumed was all spent on the carbon and hydrogen. The 16 volumes carbonic acid would require 16 volumes oxygen. There remain 8 volumes of oxygen which require 16 volumes of hydrogen. Thus it appears that the gas contains equal volumes of carbon vapour and hydrogen gas.

One volume of the gas requires for complete combustion 2 volumes oxygen gas, and forms $1\frac{1}{3}$ volume of carbonic acid gas. The remaining 0·66 volumes of oxygen gas must have combined with $1\frac{1}{3}$ volume of hydrogen gas, and formed water. Hence a volume of the gas contains

$1\frac{1}{3}$ volume of carbon vapour $\Big\}$ condensed into one volume.
$1\frac{1}{3}$ volume of hydrogen gas

Sp. gr. of $1\frac{1}{3}$ volume carbon vapour 0·5555
$1\frac{1}{3}$ volume hydrogen gas 0·0926
—————
0·6481

This subtracted from 4·1757 (the sp. gr. of the gas), leaves 3·5276, which approaches 3·3333, the sp. gr. of $1\frac{1}{3}$ volume of chlorine gas. Hence the new gas is a compound of

$1\frac{1}{3}$ volume carbon vapour, $\Big\}$ condensed in one volume. And
$1\frac{1}{3}$ volume hydrogen gas, the true specific gravity must be
$1\frac{1}{3}$ volume chlorine gas, 3·9814. I am, however, rather inclined to consider this gas as a compound of

1 volume carbon vapour	. .	0·4166
1 volume hydrogen gas	. .	0·0694
$1\frac{1}{2}$ volume chlorine gas	. .	3·7500
		4·2361

On that supposition its specific gravity would be 4·2361.

It consists of $1\frac{1}{2}$ atom chlorine, united to a compound of carbon and hydrogen, precisely the same, in the proportion of its constituents with olefiant gas, but it contains only half the number of atoms united together. Olefiant gas is a compound of two atoms carbon and 2 atoms hydrogen. But the substance in this inflammable gas, united to the chlorine, is a compound of

Atomic weights.

1 atom of carbon	. .	0·75
1 atom of hydrogen	. .	0·125
		0·875

Its atomic weight is 0·875, and its specific gravity, in the gaseous state, is 0·4861, or precisely half of the specific gravity of olefiant gas. It is to this new compound of carbon and hydrogen that I give the name of carbo-hydrogen gas. One volume of it will require, for complete combustion, $1\frac{1}{2}$ volume of oxygen gas, and it will form 1 volume of carbonic acid gas. Though carbo-hydrogen has not yet been met with, except in combination with chlorine, I see no reason why it may not hereafter be discovered in a separate state.*

Oil gas.

4. When whale oil (or indeed any fixed oil), is exposed to an incipient red heat, it is resolved into a gas, that burns with a beautiful and very strong light, and which was proposed as a substitute for coal gas, for lighting the streets, and was actually employed for some time for that purpose, though it was ultimately abandoned as too expensive. The nature of the gas from oil differs very much, according to the temperature at which it is prepared. The lower the temperature the higher is the specific gravity of the gas, and the greater is the splendour with which it burns. If the oil be exposed to a strong red heat, the gas into which it is converted is little superior to coal gas.

Trito-carbo-
hydrogen.

In the year 1820, Mr. Dalton prepared a quantity of oil

* For a more particular account of this new gas, which I discovered in 1826, and which I have called sesquichloride of carbo-hydrogen, see Phil. Trans. Edin. xi. 15.

gas in order to examine its properties. He found that 10 volumes of it required for complete combustion 30 volumes of oxygen gas, and formed 18 volumes of carbonic acid gas. But when 10 volumes of it were mixed with chlorine gas, 4 volumes only were condensed; 6 volumes remained which possessed the character of carburetted hydrogen gas. Now 6 volumes of carburetted hydrogen require, for complete combustion, 12 volumes of oxygen gas, and form 6 volumes of carbonic acid. It is clear, therefore, that the 4 volumes of gas absorbed by the chlorine, require for complete combustion, 18 volumes of oxygen gas, and form 12 volumes of carbonic acid gas. Here, then, is a gas differing completely from olefiant gas. For complete combustion, 1 volume requires 4·5 volumes of oxygen gas, and forms 3 volumes of carbonic acid gas.*

The three volumes of carbonic acid gas require for their formation, 3 volumes of oxygen gas. There remain 1·5 volumes of oxygen gas, which went to the formation of water, and must, therefore, have combined with 3 volumes of hydrogen. We see, therefore, that the gas contained in Mr. Dalton's oil gas consisted of

3 volumes carbon vapour, ⎱ condensed into ·1 volume. Its
3 volumes hydrogen gas, ⎰ specific gravity, therefore, must
be 1·4583; and it must be a compound of

3 atoms carbon	.	.	2·25
3 atoms hydrogen	.	.	0·375
			————
			2·625

Its atomic weight must be 2·625; and as the light given out, during the combustion of gases, depends chiefly upon the quantity of carbon which they contain, it is clear that this gas will emit three times as much light as carburetted hydrogen.

Dr. Henry exposed a quantity of Mr. Dalton's oil gas to the cold produced by a mixture of snow and chloride of calcium, without any sensible condensation taking place.†

Mr. Dalton has distinguished this new gas by the name of *super-olefiant gas.* But as a considerable number of gases and vapours seem to exist, distinguished from each other merely by the number of atoms of carbon and hydrogen (both equal in number), contained in a volume, it becomes necessary to

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* Phil. Trans. 1821, p. 156.
† Henry's Chemistry, i. 447.   Eleventh edition.

contrive a mode of naming them, which may be extended to any number of such compounds however great. I propose, therefore, to distinguish the simple compound of 1 atom carbon and 1 atom hydrogen, by the name of carbo-hydrogen, and to denote the number of atoms conjoined in each volume, by prefixing to that word an abbreviation of the Greek numerals. Thus

A volume of	Carbon.	Hydrogen.
Carbo-hydrogen contains	1 atom	+ 1 atom
Deuto-carbo-hydrogen or olefiant gas	2	+ 2
Trito-carbo-hydrogen or super-olefiant gas	3	+ 3

I shall have afterwards at least three more of these compounds to describe. And probably many others will be discovered hereafter. There is no great difficulty in conceiving how this aggregation of a greater and greater number of atoms, though of the same kind, should alter the nature of a body, and how, therefore, a vast number of different kinds of bodies may be formed from the union of the very same elements, only in different proportions.

The specific gravities of these three gases are as follows:

Carbo-hydrogen	. . .	0·4861 or 1
Deuto-carbo-hydrogen	. .	0·9722 or 2
Trito-carbo-hydrogen	. . .	1·4583 or 3

The quantity of oxygen consumed, and of carbonic acid formed by the combustion of a volume of each of them, is as follows:

One volume of	Oxygen in volumes.	Carbonic acid in volumes.
Carbo-hydrogen	1·5	1
Deuto-carbo-hydrogen	3	2
Trito-carbo-hydrogen	4·5	3

This view of the subject is not yet familiar to chemists. But it will ultimately throw considerable light upon the nature of many vegetable substances, which at present seem so mysterious. The oils, for example, though all of them peculiar, are composed of carbon and hydrogen in nearly the same proportions. May not some of the diversities be accounted for, by this grouping of the atoms to constitute an integrant particle of a more or less complicated nature.

5. About 12 years ago, Mr. Gordon proposed to render gas portable like lamps and candles, and thus to supersede the necessity of employing oil, or tallow, or wax for furnishing light, during the absence of the sun. His method was to condense oil gas in strong copper air-tight vessels about 30 times; so that each vessel should contain about 30 times its

volume of the gas. This gas was allowed to issue through a small stop-cock, and kindled. In this way it would burn for a considerable time, giving a regular and beautiful light. Such vessels were tried at one time instead of coach lamps, and were found to answer. I have seen one, employed in this way, burn about five hours, and it was still burning when the coach arrived in Edinburgh from Glasgow.

But when oil gas was condensed in this way, a circumstance happened which put an end to the project, by rendering the expense too great. A considerable portion of the gas lost its elastic form, and condensed into a liquid possessing the characters of a volatile oil; showing that much of the matter existing in oil gas, and which contributed to the great light which it gave out while burning, was not in the gaseous state, but in that of mere vapour. For this oil, though very volatile, did not disappear immediately when the pressure was removed, but remained in the copper vessel, and of course was lost as a combustible gas; while its condensation injured considerably the value of the compressed gas as a combustible to furnish light.

The condensation of the gas took place chiefly in a strong receiver, into which the gas was passed and compressed ; 1000 cubical feet of the gas were found to yield about a gallon of the oil. The fluid is drawn from the bottom of the receiver by opening a conical valve. At first a portion of water generally comes out, and then the liquid. It effervesces as it issues out, showing that a portion of the condensed liquid is assuming the gaseous state. Probably this effervescence is owing to the super-olefiant gas of Dalton, having been rendered liquid by a pressure of 30 atmospheres. For it is evident from Dr. Henry's experiments, that had this been the case it would assume the gaseous state again, the moment the pressure was withdrawn. The oil thus condensed, so far as I have seen it, is a transparent liquid, having a slight yellow tinge, and the smell of oil gas. Mr. Gordon put a quantity of this oil into the hands of Mr. Faraday, who subjected it to a chemical examination, and discovered that it was a mixture of a considerable number of oils, several of which he succeeded in obtaining in an insulated state, and he showed them to be definite compounds of carbon and hydrogen.* The first of these, which I shall describe, Mr. Faraday calls *carburet of hydrogen*. But it would be more accurately named *tetarto-carbo-hydrogen*, being in reality a

* Phil. Trans. 1825, p. 440.

compound of 4 atoms carbon and 4 atoms hydrogen united together to constitute an integrant particle of oil. As it is very volatile, it doubtless exists in oil gas in the state of vapour, and contributes considerably to the great light emitted by that gas during its combustion. Mr. Faraday's method of procuring this substance was the following.

Tetarto-carbo-hydrogen. The oil from the compressed oil gas was gently heated, for example, by the hand, and the vapour which passed off was made to pass through a tube cooled to zero, by being surrounded with a mixture of snow and salt, and the extremity of which is plunged into a mercurial trough. By degrees a portion of liquid is condensed in the tube, which is the tetarto-carbo-hydrogen. Its properties are as follows.

At 0° it is a transparent colourless liquid; but when slightly heated, it begins to boil, and before it has reached the temperature of 32°, it is all resolved into vapour or gas, which may be received and preserved over mercury.

This gas is transparent and colourless, and burns with a brilliant white flame. Its specific gravity, as determined by Mr. Faraday, is between 1·8751, and 1·9445, or between 27 and 28 times heavier than hydrogen gas. We shall see immediately that the true specific gravity is 1·9444. It is exactly 28 times heavier than hydrogen gas.

When cooled to 0°, it is condensed again, and constitutes a liquid whose specific gravity is only 0·627 at the temperature of 54°. A cubic inch of this liquid then weighs 158·31 grains. But a cubic inch of the vapour or gaseous body into which it is converted by heat weighs 0·6055 grain. It is evident from this, that when changed into gas it increases in bulk 261⅓ times.

The gas or vapour when agitated with water is absorbed in small quantities. Alcohol dissolves it in large quantity, and a solution is obtained, which upon the addition of water effervesces, and a considerable quantity of gas is liberated. The alcoholic solution has a peculiar taste, and does not alter vegetable blues. Olive oil dissolves six times its volume of the gas. It is not affected by alkaline solutions, nor by muriatic acid. Sulphuric acid condenses the gas in large quantity; 1 volume of acid condensing about 100 volumes of the gas. Great heat is produced; no sulphurous acid is formed; but the acid is blackened, acquires a peculiar odour, and forms a permanent compound of sulphuric acid, with carbon and hydrogen; constituting doubtless a new acid.

One volume of the gas requires for complete combustion

6 volumes of oxygen gas. Water is formed, and there is evolved a quantity •of carbonic acid gas which occupies 4 volumes. Four volumes of carbonic acid contain 4 volumes of oxygen gas. The other two volumes of oxygen gas formed water, and for that purpose must have united with 4 volumes of hydrogen gas. Hence the gas is a compound of

4 volumes carbon vapour, ⎫ united and condensed into 1 vo-
4 volumes hydrogen gas, ⎭ lume. Of course, we obtain its specific gravity by adding together four times the specific gravity of carbon vapour, and four times the specific gravity of hydrogen gas.

$$4 \text{ carbon}, \quad = 1\cdot6666$$
$$4 \text{ hydrogen}, = 0\cdot2777$$

$$\overline{}$$

$$1\cdot9444 = \text{specific gravity of the gas.}$$

It is obviously a compound of

4 atoms carbon, •	.	.	3·0
4 atoms hydrogen,	.	.	0·5

$$\overline{}$$
$$3\cdot5$$

so that its atomic weight is 3·5, and an integrant particle of it consists of 4 atoms carbon, and 4 atoms hydrogen, united together.

Like olefiant gas, it unites with its own volume of chlorine gas, and forms a transparent colourless liquid, resembling hydro-carburet of chlorine, but obviously containing twice as much carbon and hydrogen. It has a sweet taste, accompanied by an aromatic bitterness, which is very persistent. When this liquid was treated with excess of chlorine, and exposed to the light of the sun, action slowly took place; muriatic acid was evolved, and ultimately a fluid tenacious compound of chlorine, carbon, and hydrogen was formed. But no sesquichloride of carbon could be obtained. We see from this how very different tetarto-carbo-hydrogen is from olefiant gas.

6. When the oily liquid obtained by the condensation of oil gas is heated, it begins to boil at a very low temperature, but the temperature gradually rises as the process goes on, and ultimately gets as high as 260°. It is obvious from this, that the fluid is a mixture of a considerable number of liquids differing from each other in volatility. Mr. Faraday endeavoured to separate these bodies by distilling very cautiously, and changing the receiver whenever the boiling point rose 10°. Thus he obtained

a great number of liquids differing in volatility, and by rectify-
ing each of them a number of times, he brought them into a
state in which the boiling point of each was tolerably perma-
nent. He observed that the boiling point was more constant
between 176° and 190° than at any other temperature; large
quantities of the fluid distilling over without any change in
the degree, while at the other parts of the series it was con-
tinually rising.

He filled a glass tube with a quantity of liquid whose boil-
ing point was 176°, and exposing it to a freezing mixture,
sunk it to 0°. It became partly solid, crystals forming round
the side, and a fluid remaining in the centre : while two other
portions, one distilled over at 186°, and another 190°, treated
in the same way, became quite hard. The solid portion was
separated as well as possible from the liquid, and then sub-
jected to strong pressure, wrapt in blotting paper to make it as
dry and pure as possible. It was then allowed to liquefy. Its
properties were found as follows :

Properties. It is a colourless transparent liquid, whose specific gravity
at 60° is 0.85. When cooled to about 32° it crystallizes,
becoming solid. Its fusing point is very nearly 42° ; but when
liquid, it may be cooled much below its freezing point without
congealing. It contracts very much in the act of freezing, 9
parts becoming 8. So that its specific gravity in the solid
state is 0·956. At 0° it is a white transparent substance,
brittle, pulverulent, and nearly of the hardness of loaf sugar.

It evaporates entirely when exposed to the air. Its boiling
point in a glass vessel is 186°. Mr. Faraday found the
specific gravity of its vapour at 212°, to be 2·098. Hence
at 60° it would be 2.7760. We shall see immediately that
the true specific gravity at 60° is 2·7083. It is a non-con-
ductor of electricity.

It is slightly soluble in water ; but very soluble in fixed and
volatile oils, ether, alcohol, &c. the alcoholic solution being
precipitated by water. It burns with bright flame and much
smoke. When admitted to oxygen gas so much vapour rises
as to make a very powerfully detonating mixture—when passed
through a red-hot tube it deposites charcoal, and is converted
into carburetted hydrogen.

Chlorine placed in contact with it in a retort exerted but
little action till exposed to the sun's rays; when dense
fumes were formed without the evolution of much heat; and
ultimately much muriatic acid was produced, and two other sub-

stances; one a solid crystalline body, the other a thick fluid. Neither of these bodies was soluble in water; both dissolved in alcohol, the liquid readily, the solid more slowly. Mr. Faraday found them compounds of chlorine, carbon, and hydrogen; but made no attempt at a regular analysis.

Iodine did not act on the liquid in several days, excepting that it communicated to it a crimson colour. Potassium heated in it did not lose its brilliancy, or exert any action on it, at the temperature of 180°. Neither alkaline solutions nor their carbonates had any action on it. Nitric acid acted on it slowly, rendering it red, and occasioning the evolution of the odour of almonds. Sulphuric acid exerted a moderate action on it; neither heat nor sulphurous acid was evolved. But the acid acquired a light yellow colour, and a clear colourless liquid floated, which appeared to be the produce of the action. It appears, that by this liquid the nature of sulphuric acid is modified, and it becomes analogous to various other acids formed by the action of sulphuric acid on similar bodies. The nature of these acids will be described in a subsequent part of this work.

Mr. Faraday analyzed this liquid two ways. 1. 0.776 Constitution. grain of it passed through heated black oxide of copper, furnished 5·6 cubic inches of carbonic acid gas, and 0·58 grain of water. Now, 5·6 cubic inches of carbonic acid gas weigh 2·658 grains, and contain 0·725 grain of carbon, and 0.58 grain of water contain 0·064 grain of hydrogen. Hence the constituents are,

Carbon	.	.	0·725 or 1· 40
Hydrogen	.	.	0·064 or 0·125

Now 0·125 represents 1 atom of hydrogen, and 1·4 comes very nearly to 1·5, which represents 2 atoms of carbon. The reason why there is a slight deficiency of carbon, is that it was impossible to free this substance completely from the liquid with which it was mixed, and which contained less carbon than the body that becomes solid at 42°. We may then consider this substance as a compound of 2 atoms of carbon and 1 atom of hydrogen. This is the reason why Mr. Faraday has distinguished it by the name of bicarburet of hydrogen.

Mr. Faraday's second mode of analysis throws more light on the nature of this substance than the preceding one, which merely determines the ratio of the constituents, without giving us any information about the constitution of an integrant particle. He mixed the vapour of it with oxygen gas, and

detonated the mixture over mercury, determining at the same time the quantity of carbonic acid formed. The result was this, 1 volume of the vapour required 7·5 volumes of oxygen gas for complete combustion, and there were formed 6 volumes of carbonic acid gas. Now 6 volumes of the oxygen gas went to the formation of carbonic acid, the remaining 1·5 volumes of oxygen gas united to hydrogen and formed water. It is evident that the quantity of hydrogen was exactly 3 volumes. Thus we see that the vapour of bicarburet of hydrogen is composed of

6 volumes carbon vapour, ⎱ condensed into 1 volume.   Hence
3 volumes hydrogen gas, ⎰ the specific gravity of the vapour must be equal to six times the specific gravity of carbon vapour, and three times the specific gravity of hydrogen gas, added together.

$$6 \text{ carbon} \quad = 0.4166 \times 6 = 2.5$$
$$3 \text{ hydrogen} = 0.0694 \times 3 = 0.2083$$

$$\overline{ 2.7083}$$

Thus we see that the true specific gravity of the vapour is 2·7083.

The bicarburet of hydrogen of Faraday is obviously a compound of

		Atomic weight.
6 atoms carbon	. .	4·5
3 atoms hydrogen	. .	0·375
		4·875

Thus its atomic weight is 4·875, and the integrant particle contains no fewer than 9 atoms united together, constituting obviously a very complex body.

Hexacarbo-
hydrogen.

7. The portion of the distilled oil which boiled at 186°, but remained liquid, when cooled down to zero, was obviously different from the bicarburet of hydrogen. But as it retained bicarburet of hydrogen in solution, from which it was impossible to free it completely, we cannot learn its constituents with accuracy.

In its general characters of solubility, combustibility, action of potassium, &c. it agreed with bicarburet of hydrogen. Its specific gravity was 0·86 at 60°. The vapour at 212° had a specific gravity of 2·301. Hence at the temperature of 60°, the specific gravity would be 3·0555. I have little doubt that the true specific gravity at 60° is 2·9166.

Sulphuric acid acted upon it much more powerfully than upon the bicarburet of hydrogen. Great heat was evolved, much discoloration occasioned, and a separation took place into a thick black acid and a yellow lighter liquid resisting any farther action at common temperatures.

Mr. Faraday analyzed it by passing it through red-hot black oxide of copper, collecting the carbonic acid gas, and weighing the water formed. 0·64 grain thus treated gave 4·51 cubic inches of carbonic acid gas and 0·6 grain water. 4·51 cubic inches of carbonic acid gas weigh 2·141 grains, and contain 0·584 grain carbon; and 0·6 grain of water contains 0·066 hydrogen. The constituents then are

Carbon	. .	584 or 1·106
Hydrogen	. .	66 or 0·125

0·125 represents an atom of hydrogen, and 1·106 is very near 1·125, which represents $1\frac{1}{2}$ atoms of carbon. We might therefore consider this liquid portion as a sesquicarburet of hydrogen. But if we recollect that it contains an unknown proportion of bicarburet, which must of course increase the proportion of carbon, we can have little doubt that this liquid, if we could procure it perfectly pure, would be a compound of 1 atom carbon and 1 atom hydrogen.

But we have seen that the specific gravity of its vapour is about 3. It is clear therefore that a volume of it must consist of 6 volumes carbon vapour, ⟩ condensed into 1 volume. The 6 volumes hydrogen gas, ⟨ specific gravity must be

Carbon	= 0·4166 × 6	= 2·5
Hydrogen	= 0·0694 × 6	= 0·4166

$$2\cdot 9166$$

Thus we see that the true specific gravity must be 2·9166. One volume of it will require for complete combustion 9 volumes of oxygen gas, and it will leave as a residue after the combustion 6 volumes of carbonic acid gas. This liquid then might receive the name of hexa-carbo-hydrogen. It is of a very complex nature, since an integrant particle of it contains no fewer than 12 atoms united together.

8. *Naphthaline.* This substance was discovered in the year 1819, in one of the condensing vessels erected in London for the distilling of coal tar. It was first noticed, and some of its most remarkable properties determined, by Mr. Garden.* Its

* Annals of Philosophy, xv. 74.

properties were afterwards more minutely examined by Dr. Kid.* And Mr. Chamberlain has given us an account of the way in which it is obtained from coal tar.† It got the name by which it is distinguished from Dr. Kid, in consequence of its obvious connexion with coal naphtha.

How obtained. When coals are heated in iron retorts, as the mode is in order to obtain coal gas, a considerable quantity of brown coloured semifluid matter is obtained, usually distinguished by the name of *coal tar*. It is from this coal tar that *coal naphtha* and *naphthaline* are procured. To obtain naphthaline, the coal tar is subjected to distillation. The first fourth that comes over consists partly of naphtha, and partly of water, holding ammonia and naphthaline in solution. The next fourth part that comes over is a dense oil mixed with naphthaline, and the proportion of this last substance gradually increases as the distillation advances. If the remaining half be distilled over in three separate portions, it will be observed that the first of these contains but little naphthaline, the second scarcely any; but the third contains so much, that the last few gallons distilled often become solid from its crystallizing within a few hours after they have come over. The last quantity of naphthaline obtained is mixed with much sulphur. The naphthaline is deposited from the oil in imperfect crystals. It may be freed from the oil by pressing it between folds of blotting paper, and afterwards subliming it by a very gentle heat. It forms an exceedingly beautiful substance in silvery plates. By solution in hot oil of turpentine, and spontaneous crystallization, it may be obtained in transparent flat four-sided prisms, with angles approaching to 100° and 80°, and terminated by dehedral summits.

Properties. The colour of naphthaline is white with a splendent pearly lustre. Its smell is aromatic, and has been compared by Dr. Kid to that of the narcissus. Most generally it is not quite free from the smell of coal naphtha. The taste is pungent and aromatic, but disagreeable.

It is a very little heavier than water. When exposed to the air it evaporates spontaneously, but not so rapidly as camphor. It melts by my trials at 174°, and boils as Dr. Kid ascertained at 410°. But it may be sublimed at a temperature below the point of liquefaction, and it always, when so sublimed, is deposited in crystalline plates.

* Phil. Trans. 1821, p. 209.
† Annals of Philosophy (second series), vi. 135.

It does not burn readily. When heated in a platinum spoon, it is volatilized in an acrid white smoke. When this smoke is brought in contact with the flame of a candle, it catches fire, and the naphthaline burns with a strong yellow flame, at the same time emitting much smoke.

It is insoluble in cold, and very slightly soluble in hot water. It dissolves readily in alcohol and ether, and the volatile and fixed oils.

It dissolves in hot acetic and oxalic acid; but falls down again when the liquid cools. It is not acted on by alkaline solutions. When digested in nitric acid it is converted into a yellow coloured matter, having an acrid taste. This matter melts at 82°, and on cooling crystallizes in fine needles. Its specific gravity is 1·23. I do not find that this substance, which seems to be a compound of nitric acid and naphthaline, possesses acid properties.

Naphthaline dissolves in sulphuric acid. The solution is dark coloured and opaque, and Mr. Faraday has shown that it constitutes a new acid, to which the name of *sulpho-naphthalic* acid has been given.*

When naphthaline, rendered as pure as possible by repeated sublimations, is passed through red-hot black oxide of copper, it is completely decomposed, and converted into carbonic acid and water. One grain, treated in this way, yielded 3·3 grains of carbonic acid, and 0·9 grain water. Hence the constituents are,

Composition.

Carbon	.	0·9 or 1·125 = 1½ atom
Hydrogen	. .	0·1 or 0·125 = 1 atom
		1·0 1·25

Thus we see that naphthaline is composed of 1½ atoms carbon and 1 atom hydrogen. These numbers merely give the ratios of the constituents, without throwing any light upon the number of atoms of each constituent which go to the formation of an integrant particle. These are probably numerous; but cannot be known till we ascertain the specific gravity of the vapour of naphthaline. It would be premature to give this substance the name of sesquicarburet of hydrogen. Dr. Kid's name of *naphthaline* must be retained till we know more about the constitution of this substance. From Mr. Faraday's analysis of sulpho-naphthalic acid, I think it not unlikely that a volume of

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* Phil. Trans. 1826, p. 140.

the vapour of naphthaline will be found to contain 15 volumes of carbon vapour and 10 volumes of hydrogen gas. Were that the case naphthaline would be a compound of

15 atoms carbon	.	.	11·25
10 atoms hydrogen	.	.	1·25
			12·5

And an atom of it would weigh 12·5.

Coal gas. 9. Coal gas, which is now so extensively used in Great Britain for lighting the streets of all our principal towns, and is therefore become a product of great importance, is a mixture of several of the substances which have been just described as compounds of carbon and hydrogen, together with variable proportions of hydrogen and carbonic oxide gases. For the most accurate experiments on the nature and constituents of coal gas we are indebted to Dr. Henry.*

The nature of coal gas differs very much, not only according to the kind of coal employed, but according to the way in which the gas is prepared. The more quickly the heat is applied, the greater is the quantity, and the better the quality of the gas from coal. Too low a heat expels the inflammable matter in the form of tar. The first portions of gas that come over are the best, and the quality becomes gradually worse as the distillation proceeds. The last portions do not give more than half the light of the first portions. Sometimes the specific gravity is as high as 0·650; sometimes as low as 0·345. The higher the specific gravity the better always is the gas. The specific gravity of oil gas is sometimes as high as 0·906, sometimes as low as 0·590, or perhaps even lower. Coal gas in general consists of a mixture of

Its constituents.

> Olefiant gas,
> Carburetted hydrogen,
> Carbonic oxide,
> Hydrogen gas,

in various proportions; but the quantity of carburetted hydrogen is always much more considerable than that of any of the others. The vapour also of coal naphtha and naphthaline are mixed with the gas, and add something to its illuminating power. It is to the presence of these bodies that the smell of coal gas is owing. This smell is nearly removed by washing the gas with oil of turpentine or alcohol. Neither water nor

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* See Phil. Trans. 1808, 1820, and 1824.

alkalies have any effect in removing it. I have not tried acids, because sulphuric acid, the only one cheap enough for use, would destroy the gas by abstracting its portion of olefiant gas.

The following table exhibits the composition of three dif- ferent varieties of coal gas, as determined by Dr. Henry.

Sp. gravity of gas.	CONSTITUENTS IN VOLUME.				
	Olefiant gas.	Carburetted hydrogen.	Carbonic oxide gas.	Hydrogen.	Total.
0·620	12	64·53	7·33	15·84	100
0·630	12	57·49	13·35	17·16	100
0·500	7	55·80	13·95	23·25	100

Oil gas being now almost out of use, is of less importance. It obviously owes its great illuminating power to the presence of the oily substances condensed from it by pressure, and so well described by Faraday; and likewise to the super-olefiant gas of Dalton.

The following table exhibits the constituents of the best and the worst kind of oil gas, as determined by the analysis of Dr. Henry.

Sp. gravity of gas.	Super olefiant gas.	Carburet. hydrogen.	Carbonic oxide.	Hydrogen.	Total.
0·906	38	42·16	14·26	5·58	100
0·590	19	31·32	15·66	34·02	100

The illuminating power of the best oil gas is to that of the best coal gas, according to the trials of Dr. Christison and Dr. Turner, as 2·25 to 1.

VII. Carbon, so far as we know at present, combines with azote in only one proportion, and forms a compound discovered by Gay-Lussac in 1815, and which he distinguished by the name of *cyanogen.*[*]

It is easily obtained by exposing dry *prussiate of mercury* in a small retort, to a heat rather under redness; the salt blackens, and a gaseous fluid is extricated in abundance : it must be received over mercury. This gas is *cyanogen.*

This gas is colourless, and possesses the mechanical proper- ties of common air. Its smell is quite peculiar, and excessively strong and disagreeable. Its specific gravity as determined by Gay-Lussac is 1·8064. We shall see immediately that the true specific gravity is 1·8055, which almost coincides with Gay-Lussac's number.

* Ann. de Chim. xcv. 172.

Cyanogen doubtless would destroy life if the attempt were made to breathe it; though I am not aware that any living animal has been exposed to its action. It is inflammable, and burns with a purplish blue flame. It is not decomposed by exposure to a red heat. Water dissolves $4\frac{1}{2}$ times its volume, and alcohol 40 times its volume of this gas. It reddens tincture of litmus. Phosphorus, sulphur, and iodine, may be volatilized in it without alteration. Potassium burns in it and absorbs it. For complete combustion it requires twice its volume of oxygen. The products are twice its volume of carbonic acid, and

Composition. its own volume of azotic gas. Hence it is obviously composed of two volumes carbon and one volume azote, condensed into one volume, or by weight of

Azote   .   .   0·9722 or 1·75
Carbon   .   .   0·833 or 1·5

Or of two atoms of carbon united to one atom of azote. Its atomic weight therefore is 3·25.

Forms many compounds
Cyanogen has the property of combining with a great variety of bodies, and of forming compounds deserving particular attention. When united to hydrogen it constitutes *hydro-cyanic acid* or *prussic acid*. When united to *chlorine* it forms *chloro-cyanic acid;* with sulphur it forms *sulpho-cyanic acid;* and with oxygen, *cyanic acid*. There is another acid which, according to the experiments of Gay-Lussac and Liebig, is also composed of oxygen and cyanogen; but the experiments of Mr. Edmund Davy give a result somewhat different. This acid has received the name of *fulminic*. I shall reserve an account of all these acids, and indeed of all *cyanodides*, till I come to the second volume of this work, when the reader will be better able to appreciate the many curious and important, but difficult facts, connected with the formation and action of these bodies.

Dry bicarbu-ret of azote.
2. When *cyanodide of mercury*, or *prussiate of mercury*, as it was formerly called, is heated in order to obtain cyanogen, there remains in the glass retort after the gas ceases to come over a blackish matter mixed with globules of running mercury. This matter varies much in its appearance; sometimes being light and bulky, at other times looking as if it had been fused. Indeed the cyanodide liquefies and blackens fast, if the heat be applied rapidly. This substance in its purest state is brownish or reddish black. It is easily reduced to powder. When heated to redness it gives off fumes, but is dissipated very

slowly. In the flame of a lamp it is consumed very gradually without flame. In a white heat it melts and disappears pretty rapidly. It is insoluble in water, alcohol, ammonia, and nitric acid. It dissolves in hot and concentrated sulphuric and muriatic acids. When heated with chlorate of potash it detonates and is completely decomposed. This substance was subjected to analysis by Mr. Johnston, who found it a compound of carbon and azote, in the proportion of 2 atoms of the former to 1 atom of the latter.* Its constituents are therefore the same, and in the same proportion as cyanogen. Yet its properties differ so much from cyanogen that its constitution must certainly be equally different. The only supposition that we can form is that a much greater number of atoms of carbon and azote enter into the composition of an integrant particle of it than of cyanogen, though the ratio does not vary. But as it seems incapable of assuming the gaseous form we are at present unable to determine how many. The atomic weight will therefore be $3.25x$, x indicating the unknown number of particles of cyanogen that go to the formation of this *bicarburet of azote.*

3. When a saturated solution of cyanogen in alcohol is set aside, it soon becomes dark coloured and deposites a quantity of brownish matter, which is *bicarburet of azote* nearly pure. Mr. Johnston found this substance and likewise the bicarburet from the decomposition of cyanodide of mercury, when heated considerably to lose one-half of its carbon, and to be converted into a black shining matter composed of carbon and azote in the simple proportion of one atom of each, and therefore constituting a simple *carburet of azote.*† If Mr. Johnston's analysis of this substance be exact; but it was made upon too small a scale to entitle it to full confidence; it presents an anomaly not easily explained. Of the two constituents of it, carbon and azote, the one is a fixed solid and the other a gaseous body. Carbon is so fixed that we are incapable of driving it off in ordinary cases, except in combination. We can in many cases burn it away; that is, drive it off by combining it with oxygen: but in Mr. Johnston's experiment the carbon was actually volatilized alone, and the azote remained. It would be requisite that so uncommon a circumstance should be very fully established by the most convincing experiments before its truth could be admitted. It is much more likely that the carbon made its escape combined with hydrogen in the state of car-

* Brewster's Journal (2d series), i. 75.   † Ibid. p. 81.

buretted hydrogen. If so, the black matter contained hydrogen. And indeed Mr. Johnston has brought no evidence to demonstrate the absence of this substance as a constituent. It is possible also, that the carbon may have made its escape in combination with oxygen, in the state of carbonic oxide. But new experiments are still wanting to elucidate this obscure subject.

<div align="center">SECTION IV.—OF BORON.</div>

History.   The saline substance called *borax* has been long familiar to European artists, being employed to facilitate the fusion of the precious metals, and in the formation of artificial imitations of the precious stones. It comes from the East Indies, and is said to be found chiefly in certain lakes in Thibet and China.* The word *borax* occurs first in the writings of Geber, an Arabian chemist of the tenth century. In the year 1702, Homberg, by distilling a mixture of borax and green vitriol, obtained a peculiar substance in small white shining plates, which he called *sedative* or *narcotic salt*, and which was considered as an efficacious remedy in continued fevers.† Lemery, the younger, in the year 1727, found that this substance could be separated from borax by the mineral acids.‡ In 1731, Geoffroy ascertained that sedative salt gave a green colour to the flame of alcohol, and that borax contains in it the same alkaline substance that constitutes the basis of common salt.§ In the year 1752, Baron demonstrated by satisfactory experiments, that borax is composed of sedative salt and soda.‖ Sedative salt was found to possess the properties of an acid: it was therefore called *boracic acid*. But the composition of this acid remained altogether unknown. Crell, indeed, published a set of experiments on it in the year 1800, in which he endeavoured to show, that its basis was a substance very similar to charcoal in its properties.¶ But when his experiments were repeated by Sir H. Davy, they did not succeed. Davy, in the year 1807, exposed a quantity of boracic acid to the action of the galvanic battery, and observed that a black matter was deposited upon the negative wire, which he considered

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* Baron, on the authority of an Armenian merchant says, that it is collected in pits near Busrora. But I have reason to believe that he was misinformed.

  † Histoire de l'Acad. 1702, p. 50.   ‡ Mem. Par. 1728, p. 273.
  § Mem. Par. 1732, p. 398.   ‖ Savans Etrangers, ii. 412.
  ¶ Ann. de Chim. xxxv. 202.

as the basis of this acid, but he did not prosecute the disco-
very farther at the time. In the summer of 1808, MM. Gay-
Lussac and Thenard succeeded in decomposing this acid by
heating it in a copper tube along with *potassium*. They
examined the properties of its base, to which the name of *boron*
has been given, and published a detailed account of its pro-
perties.* Davy, in 1809, decomposed the acid by the process
of the French chemists, and published likewise an account of
the properties of boron.† Boron may be obtained by the fol-
lowing process.

One part of very dry and powdered boracic acid is to be
mixed with two parts of potassium, and the mixture put into a
copper or iron tube, and heated till slightly red, and kept in
that state for several minutes. A violent detonation usually
takes place, and part of the matter is driven out of the tube.
What remains is to be washed out with water, and the potash
being neutralized by muriatic acid, the whole is to be thrown
on a filter. The boron remains on the filter and is to be well
washed and dried. A more economical method of obtaining
boron, as Berzelius assures us, is to decompose an *alkaline
fluoborate*‡ by potassium. Boracic acid cannot be completely
deprived of its water. This is the reason of the violence of
the detonation when potassium and boracic acid are heated
together and the loss which is sustained.§ When fluoborate
of potash has been sufficiently dried, the sound at the instant
of reduction is scarcely audible, and for every atom of potas-
sium expended we obtain the corresponding quantity of boron.
The only disadvantage attending this operation is the difficulty
of removing the undecomposed fluoborate of potash. The
boron must be washed with a solution of sal-ammoniac and
finally with alcohol. When pure water is employed, a con-
siderable quantity passes in a dissolved state through the filter.‖
Boron, thus prepared, possesses the following properties:

It is a powder of a deep brown colour, without either taste
or smell. In close vessels it may be exposed to the most vio-

* Mem. d'Arcueil, ii. 311, and afterwards in Recherches Physico-chimi-
ques, i. 276.
† Phil. Trans. 1809.
‡ These salts will be described in a subsequent part of this work.
§ I have prepared boron by heating boracic acid and potassium both in
copper and glass tubes, and have always sustained a considerable loss.
‖ Kongl. Vetensk. Acad. Handlingar, 1824, p. 94, or Annals of Philoso-
phy (new series), x. 128.

lent heat that can be raised, without undergoing any other change, except an increase of density. When first prepared its specific gravity is 1·183.* But after exposure to a violent heat it sinks rapidly in sulphuric acid of the specific gravity 1·844. It is insoluble in water, alcohol, ether, and oils, whether cold or hot. It does not decompose water even when heated in that liquid to the temperature of 212°. Boron is a non-conductor of electricity.

Boron is not altered in common air, or oxygen gas, at the ordinary temperature of the atmosphere; but when raised to a heat not quite so high as 600°, it takes fire and burns with great splendour, absorbing at the same time oxygen. By this combustion, a portion of the boron is converted into boracic acid, which undergoing fusion, coats the boron, and keeping it from coming in contact with the oxygen, puts an end to the combustion. If this boracic acid be washed off, the boron will burn again, but requires a higher temperature. A great number of successive combustions and washings are requisite, in order to convert the whole of the boron into boracic acid. Several experiments have been made to determine the quantity of oxygen which combines with boron, and converts it into boracic acid; but none of them seem entitled to much confidence. Gay-Lussac and Thenard acidified a portion of boron by heating it in nitric acid. Five parts of boron, by this pro-

cess, were converted into 7·5 parts of boracic acid.† According to this statement, boracic acid is composed of

Boron .	100
Oxygen . .	50

But they do not put much confidence in its accuracy.

Davy found that when 30 grains of potassium were converted into potash 2·375 grains of boron were evolved.‡ Now 30 grains of potassium require six grains of oxygen to convert them into potash. If we suppose the whole of this to have been in combination with the boron, it will follow that boracic acid is composed of

Boron . .	2.375
Oxygen . .	6

He found farther that 1 grain of boron, when converted

* Roget and Dumas; Annals of Philosophy (new series), iii. 392.
† Recherches Physico-chimiques, i. 307.
‡ Davy's Lecture on some new Analytical Researches on the Nature of certain Bodies, p. 43, Phil. Trans. 1809.

into boracic acid, absorbs 5·125 cubic inches of oxygen gas or 1.773 grains. This gives us boracic acid composed of

Boron	.	.	1	or 33·68
Oxygen	.	.	1·773	or 66·32
				100·00

From direct experiments made by Berzelius on the conversion of boron into boracic acid, he has concluded that it is a compound of

Boron	.	.	31·19
Oxygen	.	.	68·81
			100·00*

But his experiments so far as he has related them, go to prove that boron when acidified combines with twice its weight of oxygen.

I have shown by experiments which I consider as decisive, that the atom of boracic acid weighs exactly three.† Now the synthetical experiments of Davy and Berzelius show that it is composed of two parts of oxygen and one part of boron. Hence it is evident that an atom of boron must weigh exactly 1, or the same as an atom of oxygen.

So far as we know at present, there is no other compound of boron and oxygen but boracic acid.

When boron is mixed with saltpetre and heated it explodes at an incipient red heat with considerable violence, the boron being converted into boracic acid. When heated with an alkaline carbonate it burns at the expense of the carbonic acid, and carbon is disengaged. When heated with a caustic alkali in a state of fusion an effervescence takes place, hydrogen gas is evolved, and the boron is acidified by the decomposition of the water which is in combination with the potash. Boron is also easily acidified when heated with nitric acid or aqua regia. _Forms boracic acid._

Boracic acid is usually in small hexagonal plates, when obtained by mixing a solution of borax with sulphuric acid, and setting the solution aside. It is then a compound of 1 atom acid and 2 atoms water. By a red heat most of the water is driven off, and the acid melts into a colourless glass. This acid has a bitterish taste, leaving an impression of sweetness.

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* Kongl. Vet. Acad. Handl. 1825, p. 85. I am not aware that the experiments on which Berzelius founds this statement, have ever been published.

† First Principles, i. 159.

It is but little soluble in water, and is an acid by no means possessed of much energy. Its properties will be described in a subsequent part of this work.

Chloride of boron.
    2. Boron combines readily with chlorine and forms an acid compound, which is in the state of a gas. It may be called *borochloric* acid. The account of this substance was published by Berzelius in the Memoirs of the Stockholm Academy for 1824.[*] Depretz claims the discovery of it in July 1823.[†] Hence it is probable that the discovery was made both by Berzelius and Depretz without any knowledge of what the other had done. Dumas discovered it also in 1826, without being aware that it had been previously examined.[‡] There are three different ways of procuring it. 1. Boron was heated by Berzelius in pure and dry chlorine gas. The boron catches fire and burns readily. The gaseous chloride of boron is received over mercury mixed with chlorine. The mercury absorbs the chlorine, and leaves the borochloric acid in a state of purity. 2. Depretz heated the boruret of iron in chlorine gas; chloride of iron was formed, and there existed a mixture of chloride of boron and chlorine, the latter of which was removed by mercury, and the acid gas remained in a state of purity. 3. Dumas mixed together very dry boracic acid and charcoal in a porcelain tube, heated the mixture to redness, and then passed a current of chlorine gas through it. The boracic acid was decomposed by the joint action of the chlorine and the charcoal, its oxygen uniting to the charcoal and forming carbonic oxide; while the chlorine united to the boron and formed the borochloric acid. The gas which is extricated is a mixture of 2 volumes of borochloric acid and 3 volumes of oxide of carbon.

Its properties.
    Borochloric acid is a colourless gas, possessing the mechanical properties of common air. It has a very strong and peculiar smell. When it comes in contact with common air it gives out thick vapours. The specific gravity of this gas as determined by Dumas is 3·942.[§] Water absorbs it with avidity; but at the same time the gas is changed into muriatic and boracic acid by the decomposition of the water. It is absorbed also by alcohol, which acquires an etherial smell. The reason of the white vapour which appears when borochloric gas is mixed with the air is, that it undergoes decompo-

* Page 96.   † Ann. de Chim. et de Phys. xxxvi. 426.
‡ Ann. de Chim. et de Phys. xxxiii. 376.   § Ibid. 380.

sition from the action of the atmosphere, muriatic acid being formed and boracic acid. When one volume of this gas is mixed with a volume and a half of ammoniacal gas, both gases lose their elasticity and are condensed into a solid salt.

Because a mixture of boracic acid and charcoal yield boro-chloric acid and carbonic oxide gases, in the proportion of 3 volumes of the former and 2 of the latter, Dumas infers that borochloric gas is a compound of 1½ volumes chlorine, and 1 volume boron condensed into 1 volume. But I do not perceive the legitimacy of the inference; unless we admit with him that boracic acid is a compound of 1 atom boron and 3 atoms oxygen, which is very far from having been proved. But as borochloric acid when absorbed by water is converted into muriatic acid and boracic acid, it is pretty obvious that it must be a compound of 2 volumes of chlorine and 1 volume of boron vapour condensed into 1 volume. For on that supposition we have

Composition.

$$\text{borochloric acid,} \begin{cases} 1 \text{ atom boron,} \\ 2 \text{ atoms chlorine.} \end{cases}$$

It will decompose two atoms water composed of

2 atoms oxygen,
2 atoms hydrogen,

which will constitute

1 Boracic acid composed of 1 boron + 2 oxygen,
4 Muriatic acid ————— 2 chlorine + 2 hydrogen.

But this supposition does not accord well with the specific gravity of borochloric acid as determined by Dumas. He found it only 3·942, whereas a gas composed of 2 volumes chlorine and 1 volume boron condensed into 1 volume, would have the specific gravity 5·5555.* If we were to suppose the gas composed of 2 volumes chlorine and 1 volume boron condensed into 1⅓ volumes, the specific gravity would be 3·7, which is below the determination of M. Dumas. The subject obviously requires farther investigation.

3. No combination between boron and bromine or iodine has been hitherto observed.

4. Boron has the property of combining with fluorine, and of forming with it a powerful acid, to which the name of *fluoboric acid* has been given. It was discovered by Gay-Lussac and Thenard in 1808, who published a detailed account of its

Fluoboric acid.

* Supposing, as is most likely, that the specific gravity of boron vapour is equal to its atomic weight multiplied by 0·5555.

properties.*   Some additional facts respecting it were after-
wards published by Dr. John Davy.†   It may be procured by
the following process.

Mix together in a retort one part of finely pounded fused
boracic acid, two parts of fluor spar in powder, and 12 parts of
sulphuric acid.   Apply the heat of a lamp.   A gas comes
over which must be collected over mercury.   It is fluoboric
acid gas.   For this process we are indebted to Dr. John Davy.
The gas obtained by this process is never pure.   It is always
mixed with fluosilicic acid, and I found it also contaminated
with sulphuric acid.   Thenard and Gay-Lussac obtained it by
mixing dry fluor spar and boracic acid together, and heating
the mixture to whiteness in a gun barrel.   But that process is
troublesome and little productive.   Perhaps the easiest method
of getting the gas pure, is to dissolve boracic acid in pure
fluoric acid, as was done by Berzelius.   A slight heat drives
off the gas which may be received over mercury.

Properties of.   Fluoboric acid thus obtained is colourless, and possesses the
mechanical properties of common air.   Its smell is similar to
that of muriatic acid, and it has an exceedingly acid taste.   It
instantly gives a red colour to vegetable blues.   Its specific
gravity, as determined by Dr. Davy, is 2·3709.‡   I obtained
the very same specific gravity in two different trials.   But
upon deducting the fluosilicic acid and sulphuric acid with
which the gas was contaminated, the specific gravity came
out 2·3622.§   Dumas determined the specific gravity of this
gas by experiment, and found it 2·3124.∥   Water, according
to Dr. Davy, absorbs 700 times its volume of this gas.   The
liquid thus obtained is of the specific gravity 1·77.   Hence it
follows that a cubic inch of water when saturated with this gas
is expanded to 1·697 cubic inch.   This liquid acid has a cer-
tain degree of viscidity, similar to that of sulphuric acid; and,
like it, requires a high temperature to cause it to boil.   It
smokes at first, and gives out about the fifth part of the gas
which it contains, but no more, when heated; like sulphuric
acid it chars animal and vegetable substances.   It forms also an
ether when distilled with alcohol.   It combines with the differ-

* Mem. d'Arcueil, ii. 317 ; and Recherchés Physico-chimiques, ii. 37.
† Phil. Trans. 1812, p. 365.
‡ Mr. Harvey lately tried the specific gravity of this gas in my laboratory,
and found it 2·3649, a result which does not differ much from that of Dr.
Davy.
§ First Principles, i. 159.   ∥ Ann. de Chim. et de Phys. xxxiii, 283.

ent bases, and forms salts called *fluoborates.* It may be passed over red-hot iron without undergoing any change. But potassium burns in it and appears to be converted into fluoride of potassium, while boron is disengaged. Sulphuric acid has the property of absorbing 50 times its volume of this gas according to the determination of Berzelius. The acid becomes viscid. When diluted with water, a white precipitate appears, which is boracic acid.

When water absorbs fluoboric acid gas, it allows a certain quantity of boracic acid to precipitate. This (if we consider fluoboric acid as a compound of fluorine and boron) must be owing to the decomposition of water. Fluoric acid must be formed, and boracic acid in the proportion of 2 atoms of the former to one of the latter. When the water becomes saturated with fluoboric acid gas, the boracic acid disappears. It would seem, therefore, that it is decomposed, and the original fluoboric acid formed again. . Berzelius is of opinion that one-fourth of the boron is precipitated in the state of boracic acid. Three-fourths of the fluoboric acid remain, and one-fourth of fluoric acid is formed. These two united together constitute what Berzelius has called hydro-fluoboric acid.

It has hitherto been impossible to analyze fluoboric acid and determine its constituents directly. But we may determine its atomic weight with considerable precision, from which we can deduce its composition with little risk of error. Dr. Davy found that fluoboric acid gas and ammoniacal gas combine with each other in the following proportions:

1. 1 volume fluoboric gas
   1 volume ammoniacal gas — forming a solid salt.

2. 1 volume fluoboric gas
   2 volumes ammoniacal gas — forming a liquid.

3. 1 volume fluoboric gas
   3 volumes ammoniacal gas — forming a liquid.

Let us substitute for these volumes the weights by employing the specific gravities of the two gases.

1. Fluoboric acid . . 2·3124 or 8·344
   Ammonia . . 0·59027 or 2·125
2. Fluoboric acid . . 2·3124 or 4·172
   Ammonia . . 1·18055 or 2·125
3. Fluoboric acid . . 2·3124 or 4·172
   Ammonia . . 1·77083 or 3·1875

It will be seen as we proceed with this work that 2 volumes of

ammonia are equivalent to an atom of that gas. But we have no means of deciding whether 1 volume or half a volume of fluoboric gas be equivalent to an atom. It is evident, however, from the preceding table, that the atom of fluoboric acid is either 8·344 or 4·172, taking Dumas' specific gravity as correct. Were we to employ the specific gravity as determined by me, the atomic weight would be 8·5 or 4·25. Unfortunately no salt composed of fluoboric acid and a base has been hitherto analyzed. We cannot therefore be certain of the atomic weight of this acid. But I am disposed, from analogy, to consider the atomic weight to be 4·25, and to reckon 1 volume of it as equivalent to an atom. If so, and if it be a compound of fluorine and boron, it must consist of

1 atom fluorine	. .	2·25
2 atoms boron	. .	2·00
		4·25

For no other proportions will agree with the atomic weight. I do not think it necessary to discuss the theoretical determinations of Berzelius and Dumas, because they are founded on suppositions which have not been proved, and which, therefore, cannot find a place in an elementary treatise on chemistry, where facts alone, not hypotheses, should be attended to. Berzelius conceives it to be a compound of

Fluoric acid	. .	47·942
Boracic acid	. .	52·058
		100

Dumas considers it as a compound of

1 atom boron	. .	0·68
3 atoms fluorine	. .	3·51
		4·19*

I by no means consider my determination as absolutely certain, till it be corroborated by direct analysis; but in point of simplicity it far excels either the elaborate deductions of Berzelius or Dumas.†

Boretted hydrogen.

5. Leopold Gmelin appears to have obtained a boretted

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* Dumas makes the atom of boron 0·68, and the atom of fluorine 1·17, guided entirely by hypothetical views.

† The reader will find Berzelius' view explained in the Kongl. Vetens. Acad. Handl. 1824, p. 68 ; and Dumas's in Ann. de Chim. et de Phys. xxxiii. 372.

hydrogen by the following process. He mixed together four parts of iron filings and one part of boracic acid, and exposed the mixture to a strong heat for half an hour in a crucible. The fused mass was dissolved in diluted muriatic acid. An effervescence took place, and boretted hydrogen gas was extricated.* This gas had the smell of common hydrogen gas from iron, mixed with somewhat of the smell of garlic. When kindled it burned with a reddish yellow flame surrounded by a green border, and white fumes made their appearance in the vessel in which the combustion took place. These were the only characters by which the presence of boron was indicated. Gmelin neither determined the specific gravity of the gas, nor made an analysis of it. His experiments therefore are sufficient only to show us that *boretted hydrogen gas* may be formed. His gas seems to have been pure hydrogen, mixed with only a small proportion of boretted hydrogen.

6. Hitherto no combination of boron with azote or with carbon has been discovered.

The affinity of boron for oxygen appears to be greater than either that of hydrogen or carbon. Accordingly at a red heat it decomposes water and carbonic acid. Indeed it has a stronger affinity for oxygen than any of the *acidifiable bases*, unless silicon constitute an exception. Accordingly it separates oxygen from all of them when assisted by a sufficiently high temperature.

SECTION V.—OF SILICON.

There is a rock, which occurs in great abundance in the primitive mountains, sometimes forming immense beds, or even whole mountains: sometimes mixed with other stony bodies, as in granite. This rock is known by the name of *quartz*. As this stone and several others which resemble it, as *flint, calcedony,* &c. have the property of melting into a *glass* when strongly heated with potash or soda, they were classed together by mineralogists under the name of *vitrifiable stones*. Mr. Pott, who first described the properties of these minerals in 1746, gave them the name of *siliceous stones*, supposing them all chiefly composed of a peculiar earth called *siliceous earth* or *silica*. This earth was known to Glauber, who describes the method of obtaining it from quartz. But it was long before its properties were accurately ascertained. Geoffroy endeavoured to prove

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that it might be converted into lime,* and Pott,† and Baume,‡ that it may be converted into alumina: but these assertions were refuted by Cartheuser,§ Scheele,‖ and Bergman.¶   To this last chemist we are indebted for the first accurate description of the properties of *silica*.**

After the discovery of the composition of the fixed alkalies by Davy, it naturally suggested itself to chemists that *silica* also was a compound of oxygen and a certain unknown base. Berzelius, by heating violently a mixture of silica, iron, and charcoal, succeeded in separating the oxygen and uniting the base of the silica to the iron.   Davy attempted to obtain the base of silica in an insulated state, by passing potassium through red-hot silica.   He by this process decomposed the silica; but the whole *silicon*,†† as the base of silica may be called, was redissolved and decomposed when water was poured on it. The reason probably was, that he had employed an excess of potassium to decompose the silica.   Berzelius afterwards succeeded in obtaining silicon in a separate state, and in determining its properties.‡‡

There are two processes by means of which this substance may be obtained in a state of purity.

1. If potassium be heated in fluosilicic acid gas,§§ the metal becomes covered with a crust which becomes gradually black, and at last breaks, while the potassium catches fire and burns with a red flame.   After the combustion a brown scoriaceous looking matter remains.   When it is thrown into water hydrogen gas is evolved with great rapidity, and a dark brown powder falls to the bottom, upon which water has no farther any action.   This powder is silicon mixed with a little fluosilicate of potash, a salt which being but little soluble in water is very difficult to wash away.   It may, however, be completely got rid of by water, though a great deal of time and much washing is necessary for the purpose.   The brown matter thus freed from fluosilicate of potash is pure silicon.

2. Another and easier process for obtaining silicon is to mix

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* Mem. Par. 1746, p. 286.   † Lithogeogn, p. iii. Preface.
‡ Man. de Chim.   § Miner. Abb.   ‖ Scheele, i. 191.
¶ Sur les Terres Geoponiques; Opusc. v. 59.   ** Ibid. ii. 26.
†† It has been usually denominated *silicium*. But as the termination *um* is used by chemists to denote metals, it is better to make *carbon, boron,* and *silicon,* which are not metallic, and which resemble each other closely, terminate in the same syllable *on,* already appropriated to *carbon.*
‡‡ Kongl. Vetensk. Acad. Handl. 1824, p. 46.
§§ This gas will be noticed in a subsequent part of this section.

fluosilicate of potash made as dry as possible without having
been ignited, with $\frac{5}{4}$ths of its weight of potassium. The mix-
ture may be made in a glass or iron tube. The mode is to
have the salt in powder and to heat the potassium till it melts.
It is then well mixed with the salt by means of an iron rod or
wire. The mixture is then heated over a spirit lamp. It
becomes all at once red-hot, the potassium burning at the
expense of the silica which it deprives of its oxygen. A
coherent mass of a liver brown colour is the result, which is a
mixture of fluate of potash and silicet of potassium, with a
portion of undecomposed fluosilicate of potash. When this
mixture is thrown into water a quantity of hydrogen gas is
suddenly given out, because the potassium of the silicet is con-
verted into potash by decomposing water, and the silicon is set
at liberty. As soon as the effervescence is over, and the liquid
has become clear, it is decanted off. The brown powder
remaining must be well washed with cold water to remove the
potash with which it is contaminated, and the fluosilicate of
potash with which it is mixed. After the potash has been well
washed away by cold water, hot water may be used to wash
away the fluosilicate of potash. When it has been completely
washed away pure silicon remains, which may be collected on
a filter and dried.

Silicon thus obtained is a powder of a deep brown colour, **Properties.**
and so similar in appearance to *boron*, that it would be very
difficult to distinguish the one from the other by their external
characters. *Silicon* is rather deeper coloured and more brown
than *boron*. It is a non-conductor of electricity. It stains the
fingers and adheres to every thing that comes in contact with
it. Like carbon and boron it may be exposed to a very high
temperature in close vessels without fusion; but becomes
harder the greater the heat to which it has been subjected.
By this treatment its properties are very materially altered.

Silicon, before it has been strongly heated, is readily com-
bustible in the air, and burns with a very lively flame. By
this combustion about one-third of it is converted into silica,
while the rest is preserved by the silica formed, preventing
the unburnt portion from coming in contact with the atmo-
sphere. When thus burnt (even when made as dry as possible
beforehand), there is always formed a certain quantity of
water, and we perceive a feeble blue flame at the surface.
This shows that it is not pure silicon, but a compound of
silicon and hydrogen. The hydrogen doubtless replaced the

potassium when the silicet of potassium was decomposed by water. It is not acted on by sulphuric acid, nitric acid, nor aqua regia, even when boiled with these acids. But liquid muriatic acid dissolves it even without the application of heat. So does a concentrated solution of caustic potash when assisted by heat. At the same time a quantity of hydrogen gas is evolved.

After silicon has been ignited, its specific gravity is higher than 1·837; for it precipitates to the bottom of concentrated sulphuric acid. It neither burns in air nor in oxygen gas, even though strongly heated in these mediums. It is not altered by the action of the blow-pipe even when mixed with chlorate of potash. Nor does it burn though it be heated to redness in saltpetre. Neither fluoric acid nor a solution of caustic potash have any action on it even at a boiling temperature. But a mixture of fluoric acid and nitric acid dissolves it with great facility, while at the same time deutoxide of azote is disengaged.

The difference between the silicon, before and after strong ignition is, that the heat drives off the hydrogen with which it was combined, and leaves the silicon pure. It may be obtained in that state by half filling a platinum crucible with it, and slowly heating it while covered with its lid. By this method the hydrogen is gradually burnt away, the heat is then to be raised to whiteness, and the crucible kept in that state for some time. The silicon, thus treated, is to be washed in fluoric acid, in order to remove any silica with which it may be mixed. Being now washed and dried it is pure.

Combines with oxygen. Silicon has a strong affinity for oxygen, but the combination does not take place except at a very high temperature. To convert it into *silica* or *silicic acid*, as it should be called, we must mix it with dry carbonate of potash or soda. When such a mixture is heated (far below redness) the silicon burns vividly, at the expense of the carbonic acid; carbonic oxide is disengaged, and the residue is tinged black by carbon deposited. If we employ a great quantity of the alkaline carbonate, combustion does not take place, and no carbon is precipitated; nothing takes place but the evolution of carbonic oxide and the conversion of the silicon into silicic acid. By this process silicate of potash or soda is formed.

Saltpetre even in a state of fusion does not act upon silicon. When we raise the heat to redness, a feeble disengagement of gas takes place. If we add a little dry carbonate of potash to the mixture, the silicon immediately detonates by decompos-

ing the carbonic acid of the carbonate. If we heat a mixture of silicon and nitre to a white heat, a very violent detonation takes place, and silicic acid is formed.

Silicon burns also with disengagement of light by decomposing the water in the fused alkaline hydrates. But it has no action on boracic acid or on borate of soda.

II. Silicon has the property, in all probability, of combining with all the supporters of combustion, though upon bromine and iodine sufficient experiments have not yet been made to enable us to affirm that it is capable of combining with these two bodies.

1. We are acquainted with only one compound of silicon *Silicic acid.* and oxygen; namely, *silica* or *silicic acid*, which is one of the most abundant substances in nature. It is a white, tasteless powder, feeling gritty between the teeth, and having a specific gravity of 2·65 according to the determination of Roget and Dumas.* When originally formed by the combustion of silicon, it was found by Berzelius so soluble in water, that the liquid when concentrated, gelatinized. But after it has been exposed to heat it loses its solubility altogether. When silica is mixed with thrice its weight of potash, or with a quantity of carbonate of potash containing thrice as much potash as the weight of the silica employed, and the mixture is exposed to a strong red heat, it fuses and assumes on cooling the appearance of glass. This glass dissolves in water. If to an aqueous solution of it we add as much muriatic acid as will saturate the alkali and concentrate the solution sufficiently, the silica assumes the form of a white translucent *jelly.* This characterizes silica. If we evaporate the whole to dryness, and wash off the salt of potash from the dry mass, the silica remains behind in the state of a very fine white tasteless powder.

Berzelius and Stromeyer made a set of experiments to *Composition.* determine the quantity of oxygen which exists in silica. They mixed together iron filings from the purest iron that could be procured, silica, and charcoal,† in the proportions of 3 iron, 1·5 silica, and 0·66 charcoal. This mixture was put into a covered crucible, and exposed for an hour to the greatest heat that could be raised in a blast furnace. By this means a combination of iron, silicon, and carbon, was formed. It was in the state of globules that had undergone complete fusion. When freed from the charcoal they were white and ductile, unless

* Annals of Philosophy (second series), iii. 392.
† Stromeyer used lamp black to get rid of the alkali which charcoal contains.

when they contained a great proportion of carbon.   When
dissolved in muriatic acid they gave out a greater proportion
of hydrogen gas than the same weight of pure iron would have
furnished.   A substance remained undissolved, which retained
the form of the globules; and which was silica, still mixed with
some iron and carbon, from which it was separated by repeated
calcination and digestion in muriatic acid.   According to
Stromeyer's experiments, the globules containing most silicon
were composed of

Iron	.	.	85·3528
Silicon	.	.	9·2679
Carbon	.	.	5·3793
			100·0000

and the globules that contained the least silicon were com-
posed of

Iron	.	.	96·1780
Silicon	.	.	2·2124
Carbon	.	.	1·6096
			100·0000*

The specific gravity of the iron was considerably reduced
by combining it with silicon.   The specific gravity of the iron
employed by Stromeyer was 7·8285.   The specific gravity of
the alloy was never higher than 7·3241, nor lower than 6·7777.
Its specific gravity was inversely as the proportion of silicon
which it contained.

There could be no·doubt, that in the alloy the silicon
existed in a state of purity, but when the compound was
dissolved in muriatic acid, the silicon combined with oxygen,
and was converted into silicon.   Both Berzelius and Stromeyer
endeavoured to determine the quantity of oxygen which
unites with silicon, and converts it into silica, by decomposing
a given weight of the alloy, and then weighing each of the
constituents separately.   The excess of weight was considered
to be the oxygen which had united with the silicon.   This
method would answer, if these experiments could be per-
formed with rigid accuracy.   But where an error amounting
only to a small fraction of a grain would make a very
material difference in the result, it is impossible to have much
confidence in the conclusions.   According to the experiments
of Berzelius silica is composed of

* Gilbert's Annalen, xxxviii. 330.

Silicon	.	.	54·66 to 52·25
Oxygen	.	.	45·34 to 47·75

100·00   100·00

According to Stromeyer, silica is composed of

Silicon	.	.	46·0069
Oxygen	.	.	53·9931

100·0000

The mean of these two sets of experiments gives us silica composed of

Silicon	.	.	100
Oxygen	.	.	102·245

After Berzelius had obtained silicon in a state of purity, he made a direct experiment to determine how much it increased in weight when converted into silica. He ignited 100 parts of silicon with carbonate of soda. The mass was super-saturated with muriatic acid, evaporated to dryness, and the residue strongly ignited. Being digested in water a grey coloured silica remained, which after washing and ignition, weighed 203·75 parts. The liquid filtered from the silica was again evaporated to dryness, and the saline residue ignited. By dissolving the fused salt in water 1·5 part more of silica was obtained, making the whole weight of silica from 100 silicon 205·25.* According to this experiment, silica is composed of

Silicon	.	.	100	or 0·95
Oxygen	.	.	105·25	or 1

If we consider silica as a compound of 1 atom silicon and 1 atom oxygen, this analysis gives us 0·95 for the atomic weight of silicon; while the mean of the experiments of Berzelius and Stromeyer on silicet of iron, gives 0·978 for that weight.

But I am satisfied that the weight of the atom of silicon Atomic weight. deduced from both of these sets of experiments, is a litle below the truth. I have shown elsewhere that the atomic weight of silica deduced from the analysis of eight different minerals is 2·00245.† This (if we suppose silica to contain 1 atom of oxygen and 1 atom of silicon) gives 1·00245 for the atom of silicon. I have shown also that the hydrates of silica which are numerous, and five of which I examined, give exactly 2 for the atomic weight of silica.‡ This would make the atom

* Kongl. Vetens. Acad. Handl. 1824, p. 63.
† First Principles, i. 171.   ‡ Ibid. p. 191.

of silicon exactly 1, a number recommended by its simplicity, and which I am disposed to consider as the true weight of that body. Silicon then not only resembles boron very closely in its properties but has also the same atomic weight with that body.

Chloride of
Silicon.

2. *Chloride of silicon.* Silicon was found by Berzelius to burn vividly when heated in chlorine gas, and to be rapidly volatilized. The compound thus formed condensed into a colourless liquid, which was *chloride of silicon.* It is very limpid and volatile, and evaporates almost instantaneously in the form of a white vapour when exposed to the open air. It boils at a temperature below 212°, and the specific gravity of its vapour, as determined by Dumas, is 5·939.* It has a suffocating odour, not unlike that of cyanogen. It reddens litmus paper very strongly, and seems therefore to possess the characters of an acid. When dropt into water it swims on the surface of that liquid. It is gradually dissolved in the water, but deposites at the same time a little silica in the form of jelly. When a drop of chloride of silicon and of water are brought into contact, muriatic acid is disengaged, and the water is converted into a jelly by the deposition of silicic acid. Thus we see that water and this chloride mutually decompose

Composition. each other. It is obvious from this that it is composed of

1 atom chlorine	. .	4·5
1 atom silicon	. .	1·
		5·5

Its atomic weight therefore is 5.5.

It is obvious that the specific gravity of the vapour of this chloride is equal to its atomic weight, multiplied by 1·1111 or 6·1111. It is precisely equal to the specific gravity of chlorine gas + the specific gravity of fluosilicic acid. Is it not a compound of 1 volume chlorine gas + 1 volume fluosilicic acid, united together, and condensed into one volume?

Potassium is not altered when mixed with chloride of silicon; but if the mixture be heated, the chloride is converted into a gas in which the potassium catches fire, and burns when the temperature becomes rather elevated.

3. We do not know at present the bromide of silicon. Berzelius did not succeed in forming an iodide of silicon when he heated silicon in iodine vapour.†

4. Silicon unites with fluorine and forms an acid gas, which

* Ann. de Chim. et de Phys. xxxiii. 367.
† Kongl. Vetens. Acad. Handl. 1824, p. 58.

was first formed by Scheele, and afterwards more particularly examined by Dr. Priestley. It has received the name of *fluo-silicic acid.* It is easily obtained by mixing together fluor spar and glass or quartz, both in fine powder in a small retort, and adding a sufficient quantity of sulphuric acid to form the whole into a semifluid magma. When heat is applied to this mixture, fluosilicic acid comes over in the form of a transparent invisible gas.

This gas is rapidly absorbed by water, while silica is deposited in a gelatinous state. Its specific gravity, as determined by Dr. Davy, is 3·5735.[*] I found the specific gravity 3·6.[†] When this gas is placed in contact with liquid ammonia, it is absorbed, and the whole silicon which it contains is deposited in the state of silica. Dr. Davy found that 40 cubic inches of the gas, when thus treated, deposite 27·2 grains of silica. On repeating the experiment, I obtained from 40 cubic inches of this gas 27·14 grains of silica; but from the difficulty of collecting the whole, it is possible that a little may have escaped me. Forty cubic inches (supposing the specific gravity 3·6) weigh 44·848 grains. Hence the gas (supposing it a compound of fluoric acid and silica) must be composed of

Fluoric acid	. .	17·648 or 1·25
Silica	. . . .	27·2 or 1·81
		44·848

These numbers, though not correct, approach near enough 1 atom fluoric acid and 1 atom of silica, to satisfy us that this must be the constitution of the acid. Or if we consider it as a compound of fluorine and silicon, its constituents must be

1 atom fluorine	. .	2·25
1 atom silicon	. .	1·00
		3·25

And its atomic weight must be 3·25. The nature and properties of this acid will be treated of more at large in a subsequent chapter of this work, when the different acid substances come under our review.

5. It is obvious from the phenomena observed, when silicet of potassium is decomposed by water that the brown coloured powder obtained, which burns so readily when heated in the open air or in oxygen gas, is a compound of silicon and hydro-

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gen; or a silicet of hydrogen probably composed of an atom of each constituent. If so, its constituents are

1 atom silicon	. .	1
1 atom hydrogen	. .	0·125
		1·125

Its atomic weight will be 1·125, and its constituents bear the same ratio to each other as oxygen and hydrogen in water.

6. We are not acquainted with any compound of silicon and azote.

7. Silicon and carbon combine when they come in contact in a nascent state. This carburet, which is a dark brown powder, burns when heated, silica and carbonic acid gas being formed, but without any sensible augmentation in weight. If we suppose the carburet of silicon to be composed of

1 atom carbon	. .	0·75
1 atom silicon	. .	1·00
		1·75

it is obvious that its atomic weight will be 1·75, and that 1·75 of it when completely burnt, would be converted into 2 of silica. Thus the augmentation of weight is but small, and if the combustion of the silica be imperfect, it may even be imperceptible.

8. No attempt has been made to combine silicon and boron. When silicic acid and boracic acid are heated together they melt, and are converted into a transparent colourless glass.

From the preceding account of silicon, its close resemblance to boron must be evident. The apparent anomaly of silicon burning vividly in a carbonated alkali, but not in saltpetre, seems to be owing to the very high temperature requisite before silicon and oxygen can combine. The nitre when slowly heated loses its oxygen before it reaches the requisite temperature. In the alkaline carbonates, the affinity of the silica for the alkali is the cause, probably, why the silicon unites to the oxygen of the carbonic acid, and burns at a comparatively low temperature.

SECTION VI.—OF PHOSPHORUS.

Formation. Phosphorus may be procured by the following process: Let a quantity of bones be burnt, or, as it is termed in chemistry, *calcined*, till they cease to smoke, or to give out any odour, and let them afterwards be reduced to a fine powder.

Put 100 parts of this powder into a basin of porcelain or stoneware, dilute it with four times its weight of water, and then add gradually (stirring the mixture after every addition) 83⅕ parts of sulphuric acid.* The mixture becomes hot, and a vast number of air-bubbles are extricated.† Leave the mixture in this state for 24 hours; taking care to stir it well every now and then with a glass or porcelain rod to enable the acid to act upon the powder.‡

The whole is now to be poured on a filter of cloth; the liquid which runs through the filter is to be received in a porcelain basin; and the white powder which remains on the filter, after pure water has been poured on it repeatedly, and allowed to strain into the porcelain basin below, being of no use, may be thrown away.

Into the liquid contained in the porcelain basin, which has a very 'acid taste, nitrate of lead,§ dissolved in water, is to be poured slowly; a white powder immediately falls to the bottom: the nitrate of lead must be added as long as any of this powder continues to be formed. Throw the whole upon a filter. The white powder which remains upon the filter is to be well washed, allowed to dry, and then mixed with about one-sixth of its weight of charcoal powder. This mixture is to be put into an earthenware retort. The retort is to be put into a furnace, and the beak of it plunged into a vessel of water, so as to be just under the surface. Heat is now to be applied gradually till the retort be heated to whiteness. A vast number of air-bubbles issue from the beak of the retort, some of which take fire when they come to the surface of the water. At last there drops out a substance which has the appearance of melted wax, and which congeals under the water. This substance is *phosphorus.*

It was accidentally discovered by Brandt, a chemist of Hamburgh, in the year 1669,‖ as he was attempting to extract

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* It would appear from the observations of M. Julien Javal, that biphosphate of lime and charcoal when heated yield most phosphorus. See Ann. de Mines. vi. 89.

† The copious emission of air-bubbles, is called in chemistry *effervescence.*

‡ Fourcroy and Vauquelin, Mem. de l'Inst. ii. 282.

§ A salt to be described in a subsequent part of this work. It answers better than acetate of lead, as was first pointed out by Giobert, and more lately by Mr. Hume. See Giobert's process, Ann. de Chim. xii. 15; and Phil. Mag. xx. 160.

‖ Homberg, Mem. Par. x. 84. An account of it is published in the Philosophical Transactions for 1681, first by Sturmius, and then by Dr. Slare.

from human urine a liquid capable of converting silver into gold.   He showed a specimen of it to Kunkel, a German che- mist of considerable eminence, who mentioned the fact as a piece of news to one Kraft, a friend of his at Dresden.   Kraft immediately repaired to Hamburgh, and purchased the secret from Brandt for 200 dollars, exacting from him at the same time a premise not to reveal it to any other person.   Soon after, he exhibited his phosphorus publicly in Britain and France, expecting doubtless that it would make his fortune. Kunkel, who had mentioned to Kraft his intention of getting possession of the process, being vexed at the treacherous con- duct of his friend, attempted to discover it himself; and about the year 1674 he succeeded, though he only knew from Brandt that urine was the substance from which phosphorus had been procured.*   Accordingly he is always reckoned, and deservedly too, as one of the discoverers of phosphorus.

Boyle likewise discovered phosphorus.   Leibnitz indeed affirms, that Kraft taught Boyle 'the whole process, and Kraft declared the same thing to Stahl.   But surely the assertion of a dealer in secrets, and one who had deceived his own friend, on which the whole of this story is founded, cannot be put in competition with the affirmation of a man like Boyle, who was not only one of the greatest philosophers, but likewise one of the most virtuous men of his age; and he positively assures us, that he made the discovery without being previously acquainted with the process.†

Mr. Boyle revealed the process to his assistant Godfrey Hankwitz, a London apothecary, who continued for many years to supply all Europe with phosphorus.   Hence it was known to chemists by the name of *English phosphorus*.‡   Other chemists, indeed, had attempted to produce it, but seemingly without success,§ till in 1737 a stranger appeared in Paris, and offered to make phosphorus.   The French Government granted him a reward for communicating his process.   Hellot, Dufay, Geoffroy, and Duhamel, saw him execute it with success; and Hellot published a very full account of it in the Memoirs of the French Academy for 1737.||

* This is Kunkel's own account.   See his Laboratorium Chymicum, p. 660. See also Wiegleb's Geschichte des Wachsthums und der Erfindungen in der Chemie, vol. i. p. 41.

† Boyle's Works abridged by Shaw, iii. 174.

‡ See Hoffman's experiments on it, published in 1722, in his Observat. Phys. Chym. Select. p. 304.

§ Stahl's Fundament. Chym. ii. 58. || Mem. Par. 1737, p. 342.

It consisted in evaporating putrid urine to dryness, heating the inspissated residue to redness, washing it with water to extract the salts, drying it, and then raising it gradually in stone-ware retorts to the greatest intensity of heat. It was disgustingly tedious, very expensive, and yielded but a small quantity of produce. The celebrated Margraf, who informs us that he had devoted himself at a very early period to the investigation of phosphorus, soon after published a much more expeditious and productive process; for the first hint of which he was indebted to Henkel. It consisted in mixing a salt consisting chiefly of lead with the inspissated urine. He even found that urine contained a peculiar salt,* which yielded phosphorus when heated with charcoal.†

In the year 1769, Gahn discovered that phosphorus is contained in bones;‡ and Scheele, very soon after, invented a process for obtaining it from them. Phosphorus is now generally procured in that manner. The process described in the beginning of this section is that of Fourcroy and Vauquelin. The usual process followed by manufacturers of phosphorus is an improvement on that of Scheele.

Soon after the discovery of phosphorus, many experiments on it were made by Slare and Boyle. Hoffman published a dissertation on it, containing some curious facts, in 1722; but Margraf was the first who investigated its effects upon other bodies, and the nature of the combinations which it forms. The subject was resumed by Pelletier, and continued with much industry and success. Lavoisier's experiments were still more important, and constitute indeed a memorable era in chemical science.

Many important experiments on phosphorus have been made still more lately by Davy, and by Gay-Lussac and Thenand. Thenard§ and Vogel‖ have made researches on the red powder which remains when phosphorus is burnt, and upon the changes produced on it by the action of light. Dulong¶ and Berzelius** have examined its combinations with oxygen; while Dumas††

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* Known at that time by the name of fusible salt of urine, now called phosphate of ammonia.

† Miscel. Berolin, 1740, vi. 54; and Mem. Acad. Berlin, 1746, p. 84; and Margraf's Opusc. i. 30.

‡ Bergman's Notes on Scheffer, p. 208. I quote the edition of 1796.

§ Ann. de Chim. xxxvi. 109.   ‖ Ibid. xxxv. 225.

¶ Ann. de Chim. et de Phys. ii. 141.   ** Ibid. pp. 151, 218, and 329.

†† Ibid. xxxi. 113.

and Rose* have made important experiments on the gaseous compounds of phosphorus and hydrogen.

1. Phosphorus is usually of a light amber colour and semi-transparent; though when carefully prepared it is nearly colourless and transparent.† When kept some time in water, it becomes opaque externally, and then has a great resemblance to white wax. Its consistence is nearly that of wax. It may be cut with a knife, or twisted to pieces with the fingers. It is insoluble in water. Its mean specific gravity, as determined in my laboratory, is 1·748.

2. It melts, according to Pelletier, when heated to 99°.‡ In my trials I found that a temperature of 108° was requisite to produce complete fusion. Care must be taken to keep phosphorus under water when melted; for it is so combustible, that it cannot easily be melted in the open air without taking fire. When phosphorus is newly prepared, it is always dirty, being mixed with a quantity of charcoal dust and other impurities. These impurities may be separated by melting it under water, and then squeezing it through a piece of clean shamois leather. It may be formed into sticks, by putting it into a glass funnel with a long tube, stopped at the bottom with a cork, and plunging the whole under warm water. The phosphorus melts, and assumes the shape of the tube. When cold, it may be easily pushed out with a bit of wood.

If air be excluded, phosphorus evaporates at 219°, and boils at 554°.§ M. Mitchelrich finds that phosphorus may be dissolved in the phosphuret of sulphur which remains liquid at common temperatures. If the phosphorus be dissolved in this liquid by the assistance of heat, it crystallizes as the solution cools, and forms large regular dodecahedrons without any modification.‖

3. Phosphorus is dissolved in a small proportion by alcohol, ether, and oils. The solutions are transparent. When the alcohol or ether is mixed with water, the phosphorus separates

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* Poggendorf's Annalen. der Physik. xiv. 183; and Ann. de Chim. et de Phys. xxxiv. 170. xxxv. 212.

†. Thenard informs us that when melted and then suddenly cooled, it becomes quite black. But again resumes its original appearance when kept melted for a short time. Ann. de Chim. lxxi. p. 109. There seems to have been something peculiar about the phosphorus which he employed.

‡ Jour. de Phys. xxxv. 380.

§ Pelletier, Jour. de Phys. xxxv. 381.

‖ Ann. de Chim. et de Phys. xxiv. 270.

and burns on the surface of the liquid. When the oily solution of phosphorus is poured upon paper and carried into a dark room, it shines vividly, provided the temperature be above 60°. But at lower temperature the light is scarcely perceptible. When sticks of phosphorus are kept in water, that liquid is slowly decomposed, an acid of phosphorus being formed, and phosphuretted hydrogen gas evolved.*

4. When used internally, it is poisonous.† In very small quantities (as one-fourth of a grain), when very minutely divided, it is said by Leroi to be very efficacious in restoring and establishing the force of young persons exhausted by sensual indulgence ;‡ that is, I suppose, in exciting the venereal appetite.

II. Phosphorus has the property of combining with oxygen and of forming various bodies which possess acid properties. Four of these have been distinguished by particular names, namely,

      1. Phosphoric acid,
      2. Phosphorous acid,
      3. Phosphatic acid,
      4. Hypophosphorous acid.

1. When phosphorus is exposed to the atmosphere, it emits a white smoke, which has the smell of garlic, and is luminous in the dark. This smoke is more abundant the higher the temperature is, and is occasioned by the gradual combustion of the phosphorus, which at last disappears altogether.

2. When a bit of phosphorus is put into a glass jar filled with oxygen gas, part of the phosphorus is dissolved by the gas at the temperature of 60°; but the phosphorus does not become luminous unless its temperature be raised to 80°.§ Hence we learn, that phosphorus burns at a lower temperature in common air than in oxygen gas. This slow combustion of phosphorus, at the common temperature of the atmosphere, renders it necessary to keep phosphorus in phials filled with water. The water should be previously boiled to expel a little air, which that liquid usually contains. The phials should be kept in a dark place ; for when phosphorus is exposed to the light, it soon becomes of a white colour, which gradually changes to a dark brown.

3. When heated to 148°, phosphorus takes fire and burns

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* Philips, Annals of Philosophy (2d series), v. 470.
† Ann. de Chim. xxvii. 87.   ‡ Nicholson's Journal, iii. 85.
§ Fourcroy and Vauquelin, Ann. de Chim. xxi. 196.

with a very bright flame, and gives out a great quantity of white smoke, which is luminous in the dark; at the same time it emits an odour which has some resemblance to that of garlic. It leaves no residuum; but the white smoke, when collected, is found to be an *acid.* Stahl considered this acid as the muriatic. According to him, phosphorus is composed of muriatic acid and phlogiston, and the combustion of it is merely the separation of phlogiston. He even declared that, to make phosphorus, nothing more is necessary than to combine muriatic acid and phlogiston.*

These assertions having gained implicit credit, the composition and nature of phosphorus were considered as completely understood, till Margraf of Berlin published his experiments in the year 1740. He attempted to produce phosphorus by combining together phlogiston and muriatic acid: but all his attempts failed, and he was obliged to give up the combination as impracticable. On examining the acid produced during the combustion of phosphorus, he found that its properties were very different from those of muriatic acid. It was therefore a distinct substance.† The name of *phosphoric acid* was given to it; and it was concluded that phosphorus is composed of this acid united to phlogiston.

But it was observed by Margraf, that phosphoric acid is heavier than the phosphorus from which it was produced; and Boyle had long before shown that phosphorus would not burn except when in contact with air. These facts were sufficient to prove the inaccuracy of the theory concerning the composition of phosphorus; but they remained themselves unaccounted for, till Lavoisier published those celebrated experiments which threw so much light on the nature and composition of acids.‡

He exhausted a glass globe of air by means of an air-pump; and after weighing it accurately, he filled it with oxygen gas, and introduced into it 100 grains of phosphorus. The globe was furnished with a stop-cock, by which oxygen gas could be admitted at pleasure. He set fire to the phosphorus by means of a burning-glass. The combustion was extremely rapid, accompanied by a bright flame and much heat. Large quantities of white flakes attached themselves to the inner surface of the globe, and rendered it opaque; and these at last became so abundant, that notwithstanding the constant supply of

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* Stahl's Three Hundred Experiments.   † Margraf's Opusc. i. 56.
‡ Mem. Par. 1778 and 1780.

oxygen gas the phosphorus was extinguished. The globe, after being allowed to cool, was again weighed before it was opened. The quantity of oxygen employed during the experiment was ascertained, and the phosphorus, which still remained unchanged, accurately weighed. The white flakes, which were nothing else than pure phosphoric acid, were found exactly equal to the weights of the phosphorus and oxygen which had disappeared during the process. Phosphoric acid therefore must have been formed by the combination of these two bodies; for the absolute weight of all the substances together was the same after the process as before it.*

Lavoisier drew, as a conclusion, from his experiments, that phosphoric acid is composed of 100 phosphorus and 154 parts of oxygen. But his mode of experimenting was not sufficiently precise to merit confidence.

1. The best way to obtain phosphoric acid is to decompose the calcined earth of bones by means of sulphuric acid. The acid liquor obtained by this process after being freed from sulphuric acid, is phosphoric acid united with a small quantity of lime. Saturate it with ammonia, and the lime will all be precipitated in the state of phosphate. Evaporate the liquid and set it aside. Numerous crystals of phosphate of ammonia are deposited. Dissolve these crystals in water; filter the solution and crystallize a second time. Expose the phosphate of ammonia cautiously to heat in a platinum or silver crucible. It soon melts, and swells, and froths, giving out water and ammonia. Continue the heat very cautiously till most of the water and ammonia is driven off, which is known by its ceasing to froth. Then raise the heat to redness. A transparent colourless liquid is thus obtained, which on cooling assumes the form of a transparent colourless glass. It is pure phosphoric acid; the properties of which will be described in a subsequent part of this work. {.sidenote Phosphoric acid.}

There cannot be the least doubt that the atomic weight of phosphoric acid is 4·5, or at least a number approaching exceedingly near to it. {.sidenote Constituents.}

From the analysis of phosphate of barytes, by Berzelius, it appears that it is composed of

Phosphoric acid	4·445
Barytes	9·5

* Lavoisier's Chemistry, Part I. chap. v.

While biphosphate of barytes was found by him to be a compound of

Phosphoric acid	.	.	8·7
Barytes	.	.	9·5

He found the constituents of sesquisilicate of barytes

Phosphoric acid	.	.	6·1
Barytes	.	.	9·5*

Now 9·5 represents an atom of barytes. It is obvious that by the first analysis the atom of phosphoric acid is 4·445; by the second $\frac{8·7}{2} = 4·35$, and the third $\frac{2}{3}$ds of 6·1 = 4·03. Of these the first analysis is most to be depended on, and from it the weight of an atom of phosphoric acid is 4·445.

From the analysis of phosphate of lead, by the same chemist, we obtain

Phosphoric acid	.	.	4.45
Protoxide of lead	.	.	14·

14 is the atomic weight of protoxide of lead, and the atomic weight of phosphoric acid is 4·45.

Berzelius found phosphate of soda composed of

Phosphoric acid	.	.	4·57
Soda	.	.	4·

The mean of these results gives the atomic weight of phosphoric acid 4·49. I found by means of nitrate of lead mixed with neutral phosphate of soda, that the exact atomic weight of phosphoric acid is 4·5.†

Mr. Clark observed that when phosphate of soda is exposed to a red heat the nature of the acid is changed. He calls the new acid *pyrophosphoric acid.* Common phosphoric acid throws down oxide of silver of a yellow colour, and the salt is not neutral. But pyrophosphoric acid throws down oxide of silver white, and the precipitate is neutral. Mr. Clark was good enough to give me a quantity of his pyrophosphate of soda. On examining it I was surprised to find that the atomic weight of pyrophosphoric acid was precisely the same as that of com-

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* Ann. de Chim. et de Phys. ii. 153.

† The number 3·5 which I gave in my First Principles, was derived from a phosphate of soda which I had in my possession, and which contained an acid of that atomic weight (probably phosphorous acid). I did not discover my error till my stock of phosphate of soda was exhausted. On getting a new portion of salt I found it to contain acid whose weight was 4·5.

mon phosphoric acid or 4·5. This result has been lately con-
firmed by the researches of Professor Stromeyer.*

2. Phosphorous acid was first obtained in a state of purity
by Sir H. Davy. When phosphorus is made to pass through
corrosive sublimate† a liquid is obtained which was first disco-
vered by Gay-Lussac and Thenard, and which Davy showed
to be a protochloride of phosphorus. When this liquid is
mixed with water it is decomposed and converted into muriatic
acid and phosphorous acid. The muriatic acid is driven off by
a moderate heat, and pure phosphorous acid remains behind,
combined with some water.‡

Berzelius dissolved 2·211 parts of protochloride of phos-
phorus in water, by which it is known, that the two constituents
are converted respectively into muriatic acid and phosphorous
acid by the decomposition of a portion of the water. He then
threw down the muriatic acid by means of nitrate of silver.
The fused chloride of silver weighed 6·915 parts.§ Now the
chlorine in 6·915 of chloride of silver amounts to 1·705.
This weight of chlorine to become muriatic acid, will require
0·0474 hydrogen. This hydrogen it obtained by the decom-
position of water, and the oxygen of the water weighing 0·3792
parts, must have united with the phosphorus, and converted it
into phosphorous acid. But the phosphorus in the chloride
was 2·211 — 1·705 = 0·506. According to this experiment,
phosphorous acid is a compound of

Phosphorus	506	or 100
Oxygen	379·2	74·940

This is in the proportion of

Phosphorus	2
Oxygen	1·5

This is confirmed by Berzelius's analysis of phosphate of lead
and phosphate of barytes. The former consisted of

Phosphorous acid	3·45
Protoxide of lead	14·
Water	0·567

While the latter contained

Phosphorous acid	3·43
Barytes	9·5
Water	1·193‖

* Ann. de Chim. et de Phys. xliii. 364.
† A substance which will be described in a subsequent section.
‡ Phil. Trans. 1812, p. 407.　§ Ann. de Chim. et de Phys. ii. 225·
‖ Ann. de Chim. et de Phys. ii. 228.

The atom of phosphorous acid by the first analysis is 3·45; by the second 3·43. There seems no reason to doubt that the true atomic weight is 3·5. Now from the analysis of Berzelius, it appears that phosphorous acid is composed of

Phosphorus	. . .	2
Oxygen	. .	1·5
		——
		3·5

If 2 represent an atom of phosphorus, then phosphorous acid must be a compound of

1 atom phosphorus	. .	2
$1\frac{1}{2}$ atom oxygen	. .	1·5
		——
		3.5

Berzelius has shown that phosphoric acid contains the same quantity of phosphorus that exists in phosphorous acid. Hence since its atomic weight is 4·5, it must be a compound of

1 atom phosphorus	. .	2
$2\frac{1}{2}$ atoms oxygen	. .	2·5
		——
		4·5

Hypophos-
phorous acid. 3. Hypophosphorous acid was discovered in 1816 by Dulong.* When phosphorus is united to lime or barytes it forms a well known compound called *phosphuret of lime* or of *barytes,* which will be described hereafter. When these compounds are thrown into water that liquid is decomposed, two acids are formed by the combination of the oxygen of the water with a portion of the phosphorus; while another portion of the phosphorus unites to the hydrogen and flies off in the state of gas. The two acids are the phosphoric and hypophosphorous, both of which combine with the lime or barytes, forming *phosphate* and *hypophosphite* of lime or barytes. The first of these salts is insoluble in water; but the second dissolves in that liquid. M. Dulong put a quantity of phosphuret of barytes into water. After the evolution of phosphuretted hydrogen gas was at an end, he filtered the liquid. It then contained a quantity of hypophosphite of barytes in solution. Into this solution he dropt cautiously sulphuric acid as long as any precipitate fell. By this means he threw down the whole of the barytes without adding any excess of sulphuric acid. The clear liquid being

* Ann. de Chim. et de Phys. ii. 141.

decanted off consisted of a solution of hypophosphorous acid in water.

M. Rose gives the following formula for preparing this acid, which he considers as preferable to that of Dulong. A quantity of barytes is put into water together with some phosphorus, and the mixture boiled. Phosphuretted gas is given out, and hypophosphite of barytes formed in the liquid. When the process is terminated, the liquid is filtered and then mixed with an excess of sulphuric acid. The sulphate of barytes formed is separated by the filter, and the liquid is placed in contact with carbonate or oxide of lead. The sulphate of lead formed remains insoluble; but the hypophosphite of lead is dissolved. The liquid is again filtered and exposed to the action of a current of sulphuretted hydrogen gas. The lead falls down in the state of sulphuret, and the hypophosphorous acid remains in the water in an insulated state.

Dulong endeavoured to determine the composition of this acid by converting it into phosphoric acid by the action of chlorine. The quantity of phosphoric acid formed, and the proportion of chlorine necessary to induce the change, gave him the data from which his conclusions were drawn. He obtained as a result that this acid is composed of

$$
\begin{array}{lr}
\text{Phosphorus} & 100 \\
\text{Oxygen} & 36 \cdot 3
\end{array}
$$

If we turn these numbers into atoms, we have

$$
\begin{array}{lr}
1 \text{ atom phosphorus} & 2 \\
\tfrac{3}{4} \text{ atom oxygen} & 0 \cdot 75 \\
\hline
& 2 \cdot 75
\end{array}
$$

or (to get rid of the $\frac{3}{4}$ths of an atom of oxygen) of

$$
\begin{array}{lr}
2 \text{ atoms phosphorus} & 4 \\
1\tfrac{1}{2} \text{ atom oxygen} & 1 \cdot 5 \\
\hline
& 5 \cdot 5
\end{array}
$$

In the former case the atomic weight will be 2·75; in the latter 5·5. As none of the hypophosphites has been subjected to analysis, we cannot determine which of these numbers is the true one.

But Dulong is uncertain whether hypophosphorous acid may not also contain hydrogen. It is obvious that we would obtain the same constituents, if we were to consider it as a compound of 1 atom phosphoric acid and 1 atom phosphuretted hydrogen.

For phosphoric acid consists of 1 atom $+ 2\frac{1}{2}$ atoms

(Phosphorus. Oxygen.)

and phosphuretted hydrogen of 1 $+ 1$ atom.

(Hydrogen.)

This would resolve itself into

1 atom hypophosphorous acid, 2 atoms $+ 1\frac{1}{2}$ atom

(Phosphorus. Oxygen.)

1 atom water,   1 atom $+ 1$ atom.

(Hydrogen.)

I consider this last view of the subject, which would remove the anamoly, as the most likely to be the true one.

4. When phosphorus is exposed to the air arranged in the inside of a funnel with a capillary beak, it gradually absorbs oxygen and moisture from the atmosphere, and a liquid drops from the funnel, which may be collected in a proper vessel. It has an acid taste, and the smell of garlic; and was at first considered as phosphorous acid. Dulong first showed that it was not phosphorous acid. He gave it the name of *phosphatic acid*. It has also been called *hypophosphoric* acid. Dulong determined its constituents by ascertaining the quantity of chlorine necessary for converting it into phosphoric acid. Thenard came to the same result by estimating the volume of oxygen gas absorbed, when phosphorus is converted into *phosphatic acid*. The constituents were found to be

Phosphorus   .   .   2
Oxygen   .   .   2·166

Now we obtain the same ratios, if we consider phosphatic acid not to be a peculiar acid, but a mixture of

2 atoms phosphoric acid
1 atom phosphorous acid.

The constituents of

(Phosphorus. Oxygen.)

2 atoms phosphoric acid, are 2 atoms $+ 5$ atoms
1 atom phosphorous acid,   1 $+ 1\frac{1}{2}$

Total   .   .   3 $+ 6\cdot5$.

Now

3 atoms phosphorus $= 6$
$6\frac{1}{2}$ atoms oxygen $. = 6\cdot5$

and dividing these values by 3, we get

Phosphorus   .   .   2
Oxygen   .   ,   2·166

Numbers representing the constitution of phosphatic acid.

Upon the whole then it seems established that the atomic weight of phosphorus is 2, and that it forms two acids with oxygen; namely, the phosphoric and phosphorous, the constituents and atomic weights of which are as follows:

1. Phosphoric acid, 1   atom phosphorus $= 2$

$2\frac{1}{2}$ atoms oxygen $= 2\cdot5$

$\overline{}$

$4\cdot5 =$ atomic weight.

2. Phosphorous acid of 1   atom phosphorus $= 2$

$1\frac{1}{2}$ atom oxygen $= 1\cdot5$

$\overline{}$

$3\cdot5 =$ atomic weight.

Hypophosphorous acid is probably a compound of

	Atomic weight.
1 atom phosphoric acid . .	$4\cdot5$
1 atom phosphuretted hydrogen . .	$2\cdot125$

$\overline{}$

$6\cdot625$

While phosphatic acid is a mixture of

2 atoms phosphoric acid

1 atom phosphorous acid.

But it is proper to mention that M. H. Rose, by experiments which appear to be decisive, has shown that the constituents of hypophosphorous acid are

2 atoms phosphorus . .	4
1 atom oxygen . .	1

$\overline{}$

5

So that its atomic weight must be 5.[*]

5. Though pure phosphorus does not take fire till it be Oxide of phosphorus. heated to 148°, it is nevertheless true, that we meet with phosphorus which burns at much lower temperatures. The heat of the hand often makes it burn vividly; nay, it sometimes takes fire when merely exposed to the atmosphere. In all these cases the phosphorus has undergone a change. It is believed at present, that this increase of combustibility is owing to a small quantity of oxygen with which the phosphorus has combined. Hence, in this state, it is distinguished by the name of *oxide of phosphorus*. When a little phosphorus is exposed in a long narrow glass tube to the heat of boiling water, it con-

* Ann. de Chim. et de Phys. xxxv. 429.

tinues moderately luminous, and gradually rises up in the state of a white vapour, which lines the tube. This vapour is the *oxide* of phosphorus. This oxide has the appearance of fine white flakes, which cohere together, and is more bulky than the original phosphorus. When slightly heated it takes fire, and burns brilliantly. Exposed to the air it attracts moisture with avidity, and is converted into an acid liquor.* When a little phosphorus is thus oxidized in a small tin box by heating it, the oxide acquires the property of taking fire when exposed to the air. In this state it is often used to light candles under the name of *phosphoric matches ;* the phosphorus being some-times mixed with a little oil, sometimes with sulphur.

When phosphorus is long acted on by water, it is covered at last with a white crust, which is also considered as an oxide of phosphorus; but it differs considerably from the oxide just described. It is brittle, less fusible, and much less combustible than phosphorus itself.† Phosphorus, when newly prepared, usually contains some of this last oxide of phosphorus mixed with it; but it may be easily separated by plunging the mass into water heated to about 108°. The phosphorus melts, while the oxide remains unchanged, and swims upon the surface of the melted phosphorus.

The red substance formed when phosphorus burns in a con-fined place, and which remains behind after combustion in glass jars, is also considered as an oxide of phosphorus. All these bodies contain very little oxygen.

Chlorides.   III. Phosphorus has the property of uniting in two propor-tions with chlorine, and of forming two compounds, which have received the names of *sesquichloride* and *perchloride* of phosphorus.‡

1. When phosphorus is introduced into chlorine gas it takes fire and burns with a pale bluish white flame, giving out but little light. A white matter sublimes and coats the inside of the glass vessel. If the quantity of phosphorus be considera-ble there is formed at the same time towards the end of the combustion a small quantity of liquid. The combustion of phosphorus in chlorine had been repeated a great number of times by almost every chemist ever since the discovery of

---

* Steinacher, Ann. de Chim. xlvii. 104.   † Ibid.

‡ Sir H. Davy has given to these bodies the names of *phosphorane* and *phosphorana*. But his nomenclature has not been adopted by chemists. See Phil. Trans. 1812, p. 412.

chlorine gas. But nobody thought of examining the nature of the products till Sir H. Davy advanced the theory that chlorine is a simple body.

2. The *sesquichloride of phosphorus* was first prepared in quantities, and examined by Gay-Lussac and Thenard.* But Davy first ascertained its constituent parts.† It is easily obtained by passing phosphorus through *corrosive sublimate* heated in a glass or porcelain tube. The method is to take a glass tube shut at one end, to put into its bottom a quantity of phosphorus, and then to fill up a considerable part of the tube with corrosive sublimate. Heat the portion of the tube containing the sublimate; then, by applying a few bits of red-hot charcoal to the extremity of the tube, cause the phosphorus to pass in vapour through the sublimate. A bent tube must be luted to the other extremity of the glass tube, which must pass into a proper receiver. A liquid collects in this receiver, which is the *sesquichloride of phosphorus*.

This liquid is colourless like water, smokes strongly when it comes into the atmosphere, and has an acid and very caustic taste. Its specific gravity is 1·45.‡ It may be kept in close vessels without alteration. But in the open air it is speedily dissipated, leaving behind it a quantity of phosphorus. It has the property of dissolving phosphorus. When paper is dipped into this solution and exposed to the air it speedily evaporates, leaving a quantity of phosphorus which soon takes fire and burns the paper. It was in this state that it was first obtained by Gay-Lussac and Thenard. When dropped into water it is converted into muriatic and phosphorous acids. This liquid by evaporation furnishes a thick fluid, which crystallizes on cooling and forms transparent parallelopipedons. These crystals are compounds of phosphorous acid and water. When they are distilled in close vessels they give out a gas which is a compound of hydrogen and phosphorus. Phosphoric acid remains behind in the retort. From Davy's experiments it follows, that these crystals are composed of 4 parts phosphorous acid and 1 part of water.§ He endeavoured to ascertain the composition of sesquichloride of phosphorus by dissolving a given quantity of it in water, and throwing down the muriatic acid formed by means of nitrate of silver. 13·6 grains of sesquichloride treated in this way gave 43 grains of horn silver.‖

* Recherches Physico-chimiques, ii. 98, 176.
† Phil. Trans. 1812, p. 406.   ‡ Davy. Ibid.
§ Davy. Ibid. p. 408.   ‖ Ibid. p. 407.

Now 43 grains of horn silver contain 10·6 grains of chlorine. Hence the chloride is composed of

Chlorine	. .	4·5
Phosphorus	. .	1·26

Berzelius likewise has given us an analysis of this chloride of phosphorus, made precisely in the same way as Davy's. He found its composition to be as follows :*

Chlorine	. .	4·5
Phosphorus	. .	1·335

But he has since satisfied himself that the true constituents are

Phosphorus	. .	2
Chlorine	. .	6·7698

Now this is obviously a compound of

1 atom phosphorus	. .	2
$1\frac{1}{2}$ atom chlorine	. .	6·75
		8·75

It is therefore a sesquichloride of phosphorus, and its atomic weight is 8·75.

Perchloride. 3. The perchloride of phosphorus may be formed by burning phosphorus in dry chlorine gas, in the proportion of one grain of the former to about 12 cubic inches of the latter. It is a snow-white substance, exceedingly volatile, rising at a temperature below that of boiling water. Under pressure it may be fused, and then crystallizes in prisms that are transparent. When thrown into water it acts with great violence, the water is decomposed, and phosphoric acid and muriatic acid formed. It seems to possess acid properties, for its vapour reddens paper stained blue with litmus, and burns when lighted in the open air. When passed through a red-hot tube with oxygen gas it is decomposed, phosphoric acid being formed and chlorine disengaged. From the experiments of Davy, to whom we are indebted for all the preceding facts, it follows that 2 grains of phosphorus, when converted into perchloride, combines with $13\frac{1}{4}$ grains of chlorine.† Hence we see that it is a compound of 1 atom phosphorus and 3 atoms chlorine. For

1 atom phosphorus	=	2
3 atoms chlorine	=	13·5
		15·5

Numbers which approach very nearly to those of Davy.

* Ann. de Chim. et de Phys. ii. 225. † Phil. Trans. 1812, p. 406.

But there can be no doubt that the weight of chlorine as stated by Davy is a little in excess. For when perchloride of phosphorus is mixed with water a double decomposition takes place, and the whole is converted into phosphoric acid and muriatic acid. Now the phosphorus to become phosphoric acid must have combined with $2\frac{1}{2}$ atoms of oxygen, $2\frac{1}{2}$ atoms of hydrogen must have been disengaged and have formed muriatic acid by combining with $2\frac{1}{2}$ atoms of chlorine. The perchloride of phosphorus then must be a compound of

1 atom phosphorus	. .	2
$2\frac{1}{2}$ atoms chlorine	. .	11·25
		———
		13·25

And its true atomic weight must be 13·25.

IV. Balard has shown that bromine unites with phosphorus in two proportions, forming a protobromide which is liquid, and a perbromide which is solid.

When dry phosphorus is dropt into bromine in a glass tube the action is very violent, heat and light being evolved. An explosion sometimes takes place, and the whole contents are driven out of the tube. It is best therefore to make the mixture of these two bodies upon a small scale. Two compounds are formed; namely, a solid body which sublimes and crystallizes in the upper part of the vessel, and a liquid which occupies the under part of the vessel. The former contains most bromine. For the liquid may by the addition of bromine be converted into the solid.

1. The liquid, to which Balard has given the name of *pro-* *tobromide of phosphorus,* does not lose its fluidity when cooled down to 10°·5. It very slightly reddens litmus paper, owing probably to the presence of a little water in the materials from which it was prepared. It is very volatile and emits pungent vapours, when left in an open vessel. It is capable of dissolving an excess of phosphorus. Hence, when dropt upon paper, and allowed to evaporate, it sets it on fire. When mixed with water, great heat is evolved, and hydrobromic acid formed; which may be obtained in the gaseous state, if only a few drops of water be mixed with protobromide. When the liquid is evaporated to dryness, a slight combustion takes place, and phosphoric acid remains. From this, it is probable that by water protobromide of phosphorus is converted into hydrobromic acid and phosphorous acid. If so the protobromide is a compound of

$$1\tfrac{1}{2} \text{ atom bromine} \qquad . \quad . \qquad 15$$
$$1 \text{ atom phosphorus} \qquad . \quad . \qquad 2$$
$$\overline{}$$
$$17$$

and its atomic weight is 17.   It would be a sesquibromide of phosphorus.   For

	Bromine.	Phosphorus.
2 atoms sesquibromide give	3 atoms $+$	2 atoms

	Hydrogen.	Oxygen.
3 atoms water consist of	3 atoms $+$	3 atoms.

The 3 atoms bromine uniting with the 3 atoms hydrogen, would form hydrobromic acid, while the 2 atoms phosphorus uniting with the three oxygen, would form phosphorous acid. Thus the protobromide would agree in composition with the protochloride of phosphorus.

Perbromide.   2. The solid bromide of phosphorus has a yellow colour. When slightly heated it melts into a red liquid, which gives out vapours having the same colour.   When these vapours are condensed they crystallize in long needles.   But when the fused bromide is allowed to cool it forms rhomboidal crystals, the angles of which have not been measured.

The metals decompose this bromide, producing bromides and probably phosphurets.   When left in an open vessel it exhales dense and pungent vapours.   When mixed with water a double decomposition takes place, hydrobromic acid and phosphoric acid being formed.   It is obvious from this that it is a compound of

$$2\tfrac{1}{2} \text{ atoms bromine} \qquad . \quad . \qquad 25$$
$$1 \text{ atom phosphorus} \qquad . \quad . \qquad 2$$
$$\overline{}$$
$$27$$

And that its atomic weight is 27.   For

	Phosphorus.	Bromine.
2 atoms bromide contain	2 atoms $+$	5 atoms

	Oxygen.	Hydrogen.
5 atoms water contain	5 atoms $+$	5 atoms.

The 5 bromine uniting with the 5 hydrogen form hydrobromic acid; while the 2 phosphorus and 5 oxygen form phosphoric acid.*

Thus the constitution of the oxides, chlorides and bromides of phosphorus, is the same.

* Balard; Ann. de Chim. et de Phys. xxxii. 373.

The bromides of phosphorus are decomposed by chlorine; but not by iodine. Indeed, the iodides of phosphorus are decomposed by bromine. So that the order of the affinities of the *supporters* for phosphorus is

Phosphorus,

Oxygen,

Chlorine,

Bromine,

Iodine.*

V. Iodine and phosphorus combine together when mixed, with the evolution of much heat; but no light, and the compound always enters into a state of fusion. As the iodides formed have the property of dissolving both iodine and phosphorus, it is not easy to determine the proportions of the constituents. But two compounds are easily distinguished by their different characters. Iodides.

1. When 2 parts by weight of phosphorus are brought in contact with 24 parts of iodine in a glass tube, they unite with great rapidity, and the product is a reddish brown solid body which melts when heated to the temperature of about 84°. Water decomposes this compound and converts it into hydriodic acid and phosphorous acid. It must therefore have been a compound of Sesquiodide.

$1\frac{1}{2}$ atom iodine   .   .   23·625

1   atom phosphorus .   .   .   2

_____

25·625

And its atomic weight must be 25·625.

2. When 2 parts by weight of phosphorus are mixed with 40 parts of iodine, the combination takes place with equal violence; but the iodide is black, and does not melt till heated to 115°. When dissolved in water, it is decomposed and converted into hydriodic acid and phosphoric acid. Hence its constituents must be Periodide.

$2\frac{1}{2}$ atoms iodine,   .   .   39·375

1 atom phosphorus,   .   .   2

_____

41·375

And its atomic weight must be 41·375.

3. We may also form a compound of phosphorus and iodine in the proportion of Protiodide.

* This is conformable to the table in page 49 of this volume.

1 atom of phosphorus	. .	2
1 atom iodine	. . .	15·75
		17·75

The colour of this compound is orange, and it does not melt till heated to 212°. It may be sublimed unaltered, and when dissolved in water is decomposed into hydriodic and phosphorous acids, a little red coloured phosphorus being left behind.

The peculiar properties of this substance render it probable though it has not been analyzed, that it is a compound of 1 atom iodine, and 1 atom phosphorus. We are still ignorant of the analogous oxide, chloride and bromide of phosphorus; but they will doubtless be discovered hereafter.

Fluoride.   VI. From the experiments of Davy, there seems little doubt that phosphorus may be combined with fluorine. His method was to mix fluate of mercury, or fluate of lead* with mercury, and to distil the mixture in a vessel of platinum. There was formed a metallic phosphuret while the fluoride of phosphorus was volatilized. It is a fuming liquid, capable of taking fire and burning in oxygen gas. When mixed with water it is decomposed and converted into hydrofluoric acid and phosphorous acid. Hence it must have been a compound of

1½ atom fluorine	. .	3·375
1 atom phosphorus	. .	2
		5·375

And its atomic weight must be 5·375. It is therefore a sesquifluoride, and quite analogous to the similar compounds of phosphorus with oxygen, chlorine, bromine, and iodine.

VII. Phosphorus combines with hydrogen in various proportions; two of which, distinguished by the names of *phosphuretted hydrogen* and *hydrophosphoric gas*, have been particularly examined.

Phosphuretted hydrogen.   1. Phosphuretted hydrogen gas, the first of these compounds, was discovered in 1783 by M. Gengembre, while heating a mixture of liquid potash and phosphorus in a small retort. He made some experiments on this remarkable gas, and published an account of its properties.† Some experiments were made upon it in 1786 by Mr. Kirwan,‡ who discovered it

---

* There is little doubt that these salts are in reality *fluorides of mercury and lead.*

† Memoires des Savans Etrangers, x. 651.

‡ Phil. Trans. 1786, p. 118.

without being aware that it had been already made known to chemists by M. Gengembre. In 1791, M. Raymond pointed out a method of preparing it in greater quantities by heating a mixture of phosphorus and quicklime.* And, in 1799, he described the properties of a solution of this gas in water.† Mr. Dalton, in his *New System of Chemical Philosophy*, published in 1810, gives an account of a set of experiments to which he subjected it in order to determine its nature and composition.‡ And, in 1816, I published a set of experiments which I had made on it.§ In 1826 an elaborate and excellent paper was published on it by Dumas.‖ And about the same time it was examined with much skill and address by M. H. Rose.¶

2. Phosphuretted hydrogen may be obtained by the following process: Fill a small retort with water, acidulated by muriatic acid, and then throw into it a quantity of phosphuret of lime in lumps. Plunge the beak of the retort under water, and place over it an inverted jar filled with that liquid. Phosphuretted hydrogen gas is extricated in considerable quantity and soon fills the glass jar. Half an ounce of phosphuret of lime yields about 70 cubic inches of this gas. When prepared by mixing phosphuret of lime with water, which was the process that I followed, Dumas has shown that it is a mixture of phosphuretted hydrogen and pure hydrogen gases, in the proportion of about 87 volumes of phosphuretted hydrogen, and 13 volumes of pure hydrogen gases. When phosphuretted hydrogen gas is obtained by boiling phosphorus in a solution of caustic potash, Dumas found the gas evolved to be a mixture of

Volumes.
37·5 phosphuretted hydrogen
62·5 hydrogen gas

——————

100·0

When prepared by mixing phosphuret of barytes and water, the gas evolved was a mixture of

Volumes.
56·8 phosphuretted hydrogen
43·2 hydrogen gas

* Ann. de Chim. x. 19.   † Ibid. xxxv. 225.
‡ Vol. II. p. 457.   § Annals of Philosophy, viii. 87.
‖ Ann. de Chim. et de Phys. xxxi. 113.
¶ Ibid. xxxiv. 170, and xxxv. 212.

When a mixture of phosphorus and milk of lime was employed, the gas evolved was exceedingly various in its proportions. At first it was a mixture of

Volumes.

66 phosphuretted hydrogen
34 hydrogen gas

——————

100

But the proportion of hydrogen increased as the process went on, and at last it was a mixture of

Volumes.

14 phosphuretted hydrogen
86 hydrogen gas

100

The purity of the gas is easily determined by means of a saturated solution of sulphate of copper, which absorbs the phosphuretted hydrogen, and leaves the hydrogen gas, or azotic gas (should any be present), untouched.

Properties.   3. Phosphuretted hydrogen gas is colourless, and possesses the mechanical properties of air. It has a smell similar to that of onions, and an exceedingly bitter taste. It may be kept in pure water without alteration; but in water containing common air it soon loses a portion of its phosphorus, and its properties are altered in consequence. Its specific gravity, as determined by Dumas, is 1·761.* We shall see immediately that the true specific gravity is 1·7708.† Dumas has shown that when this gas is heated along with corrosive sublimate, it is completely decomposed, and a quantity of muriatic acid gas formed, amounting to three times the volume of the phosphuretted hydrogen gas decomposed. Now muriatic acid contains half its volume of hydrogen gas. From this it is evident that a volume of phosphuretted hydrogen gas contains $1\frac{1}{2}$ volume of hydrogen gas. The rest is phosphorus. And the quantity of phosphorus present in the gas may be determined by subtracting the weight of $1\frac{1}{2}$ volume hydrogen gas from the specific gravity of phosphuretted hydrogen gas.

———————————————

* Ann. de Chim. et de Phys. xxxi. 149.

† I found its specific gravity in one experiment, 0·9022; and in another, 0·904; but I was not aware that the gas which I examined contained a mixture of 13 per cent. of hydrogen gas. This mixture, to which I did not advert, vitiates all my results.

Sp. gr. of phosph. hydr.   .   .   1·761

———— 1½ hydrogen gas   .   .   0·10416

———————

1·65684

From this it appears that phosphuretted hydrogen is com-
posed of

Hydrogen   .   .   1·0416

Phosphorus   .   .   165684

Now these numbers are to each other as 0·125 to 1·988.   It
is obvious from this that phosphuretted hydrogen is a com-
pound of

1 atom hydrogen   .   .   0·125

1 atom phosphorus   .   .   2·

———————

2·125

And that its atomic weight is 2·125.   The reason why the
quantity of phosphorus is a little under an atom is obviously
that Dumas has slightly underrated the specific gravity of the
gas.   Had the specific gravity of the gas been 1·77083, then
the constituent would have been exactly 1 atom of hydrogen
and 1 atom of phosphorus.   The constituents in that case
would be

Phosphorus   .   .   1·66666 or 2·

Hydrogen   .   .   10416 or 0·125

I found that when sulphur was heated in this gas the bulk was
not altered, though the gas was converted into sulphuretted
hydrogen.   But Dumas has accounted for this, by showing
that when the proportion of sulphur employed is great, a por-
tion of the gas is absorbed by the sulphur, which prevents the
increase of volume from being observed.   As I employed a
great excess of sulphur this doubtless was the cause why I did
not observe any increase of volume.   I repeated the experi-
ments more lately with the very same result; but I employed
a still greater proportion of sulphur with a view of being cer-
tain that all the phosphuretted hydrogen should be converted
into sulphuretted hydrogen.   Thus the method taken to ensure
success was the cause of my not observing the increase of
volume which would otherwise have taken place.*

When phosphuretted hydrogen comes in contact with com-

———

* I found that electric sparks caused a deposition of phosphorus without
any alteration in the volume of the gas.   Doubtless I had merely changed
the gas into sesquihydret of phosphorus, in which case the volume would
not have been altered.

mon air, it takes fire and burns with great splendour.   Yet in a narrow tube it may be mixed with oxygen gas without undergoing spontaneous combustion.   But it is deprived of its phosphorus without undergoing any alteration in its bulk.   For complete combustion, according to the experiments of Dumas, 1 volume of this gas requires 1·874 volumes of oxygen gas.   The produce is water and phosphorous acid.   Now as 1 volume of the gas contains $1\frac{1}{2}$ volume of hydrogen gas, it is clear that 0·75 volume of oxygen will go to the formation of water.   Hence the volume of oxygen gas which combines with the phosphorus must be 1·125.   Now 1·125 volume of oxygen is equivalent to $2\frac{1}{4}$ atoms which have united with the phosphorus in a volume of phosphuretted hydrogen, and converted it into phosphorous acid.   But phosphorous acid being a compound of 1 atom phosphorus $+$ $1\frac{1}{2}$ atom oxygen, it is obvious that $2\frac{1}{4}$ atoms of oxygen will convert $1\frac{1}{2}$ atoms of phosphorus into phosphorous acid.   Such therefore must be the quantity of phosphorus in a volume of this gas.

It is a law that holds pretty generally, that if we multiply the atomic weight of a body by 0·5555, the product will be the specific gravity of the body in the state of vapour.   2, the atomic weight of phosphorus multiplied by 0·5555 gives 1·1111, which must be the specific gravity of phosphorus in the state of vapour.   But the weight of the phosphorus in a volume of the gas is 1·6666.   Now this is equivalent to a volume and a half of phosphorus.   Thus it appears that phosphuretted hydrogen gas is a compound of

$1\frac{1}{2}$ volume phosphorus, $\Big\}$ united together and condensed into
$1\frac{1}{2}$ volume hydrogen, $\Big\}$ 1 volume.

It is in fact then a compound of

$1\frac{1}{2}$ atom phosphorus	.	3
$1\frac{1}{2}$ atom hydrogen	.	0·375
		———
		3·375

And its true atomic weight, instead of 2·125, is 3·1875.   It approaches therefore olefiant gas in its nature, and probably various other combinations of phosphorus and hydrogen in the same ratio, but containing a greater number of atoms united, will be discovered, as has been the case with compounds of carbon and hydrogen in the ratio of equality.

It is obvious that 1 volume of phosphuretted hydrogen will burn also with 2·625 volumes of oxygen gas, and be converted into water and phosphoric acid.   0.75 of the oxygen in this

case also go to the formation of water. Hence 1·875 volumes of the oxygen united to the phosphorus, and converted it into phosphoric acid. Now 1·875 volumes of oxygen gas is equivalent to 3·75 atoms, which is just the quantity that would be requisite to convert $1\frac{1}{2}$ atom phosphorus into phosphoric acid.

Phosphuretted hydrogen gas may be detonated also with protoxide and deutoxide of azote. The proportions of these gases requisite for complete combustion, as determined by me, would require to be modified, as I did not take into view the proportions of hydrogen gas with which the phosphuretted hydrogen was mixed. When deutoxide of azote and phosphuretted hydrogen gas are mixed over water, and a bubble of oxygen gas is let up, a detonation immediately takes place.

When phosphuretted hydrogen gas is mixed with chlorine gas, it burns with a greenish yellow flame; and when the two gases are mixed in the proportion of 1 volume of the former to 3 of the latter, they disappear entirely, being converted into muriatic acid, and a brown matter which speedily dissolves in water, and which is doubtless a bichloride of phosphorus.

When iodine is heated in phosphuretted hydrogen gas, iodide of phosphorus is formed, and probably hydriodic acid; for when water is present the bulk of the gas diminishes one-third.

Water, according to the experiments of Dr. Henry, dissolves rather more than 2 per cent. of this gas. The water acquires a yellow colour, an intensely bitter taste, and a smell similar to that of the gas. It produces no alteration on vegetable blues, but precipitates silver, mercury, and copper, from their solutions of a dark colour.

Bromine probably is capable of decomposing this gas without the aid of heat. But iodine produces no alteration on it unless heat be applied. It unites readily with hydriodic acid, and forms a solid white substance which crystallizes in cubes, and is easily decomposed by water. According to Dumas this compound consists of 1 volume of hydriodic acid and half a volume of phosphuretted hydrogen united together. Doubling these volumes, we have a compound consisting of

$1\frac{1}{2}$ atom phosphorus	. .	3
2 atoms iodine	. .	31·5
$3\frac{1}{2}$ atoms hydrogen	. .	0·4375
		————
		34·9375

So that its atomic weight is 34·9375. This is a very singular

compound, when we attend to its atomic structure. But the best way is to view it as a compound of

1 atom hydriodic acid	.	15·875
½ atom phosphuretted hydrogen	.	1·59375
		17·46875

For unless we consider these compound bodies to unite precisely as simple substances, our views will become too complicated for any purpose of utility.

This gas when kept very soon deposites one-third of its phosphorus, and is converted into the hydro-phosphoric gas of Davy, or the *sesquihydret of phosphorus,* as it ought to be called.

Sesquihydret
of phosphorus. 2. *Hydro-phosphoric gas,* or *sesquihydret of phosphorus,* was first particularly examined by Sir H. Davy in 1812.*

He obtained it by heating crystallized phosphoric acid. It may be procured, also, by exposing phosphuretted hydrogen to the direct rays of the sun. A quantity of phosphorus is deposited, and the gas is changed into *sesquihydret of phosphorus.*

This gas is colourless, and possesses the mechanical properties of common air. Its smell is similar to that of phosphuretted hydrogen, but not so disagreeable. It may be mixed with common air or oxygen gas without burning spontaneously; but M. Houton Labillardiere discovered that combustion takes place if the pressure be diminished. His method of proceeding was this, he mixed the gas with oxygen gas or common air in a Volta's eudiometer over mercury, then raising the eudiometer till the surface of the mercury within it was about 8 inches higher than the surface of the mercury in the trough, detonation took place provided the temperature was as high as 68°. If the temperature be lower the gas must be still more rarefied before combustion will take place.

The refractive power of this gas, as determined by Dulong, is 2·682, that of air being 1.†

When corrosive sublimate is heated in this gas decomposition takes place, and a quantity of muriatic acid is evolved, equal, as determined by Dumas, to thrice the volume of the sesquihydret decomposed. From this it is obvious that 1 volume of sesquihydret of phosphorus contains a volume and a half of hydrogen.

For complete combustion a volume of this gas requires

* Phil. Trans. 1812, p. 406.   † Ann. de Chim. et de Phys. xxxi. 167.

either $1\frac{1}{2}$ volume or 2 volumes of oxygen gas. In the first
case water and phosphorous acid, in the other water and
phosphoric acid are formed. Now $1\frac{1}{2}$ volume of hydrogen gas
combine with 0·75 volume of oxygen to form water. There
remain to combine with the phosphorus 0·75 volume or 1·25
volume of oxygen. But 0·75 volume of oxygen is equal to
$1\frac{1}{2}$ atom, while 1·25 volume represents $2\frac{1}{2}$ atoms. Now these
are the quantities requisite for converting 1 atom of phosphorus
into phosphorous or phosphoric acid respectively. We have
seen already that 1 atom of phosphorus may be represented by
a volume ; and that the specific gravity of phosphorus vapour
is 1·1111. It is obvious from all this that a volume of sesqui-
hydret of phosphorus is composed of

$1\frac{1}{2}$ volume hydrogen	. .	0·10416
1 volume phosphorus	. .	1·11111
		1·21527

Hence the true specific gravity of this gas must be ·1·21527.
Now Dumas took the specific gravity with much care, and
found it 1·214,[*] which differs from the theoretical number by
less than $\frac{1}{1000}$th part. Leaving no doubt about the accuracy
of our determination. The difference between phosphuretted
hydrogen and sesquihydret of phosphorus is that the latter con-
tains half a volume of phosphorus less than the former. This
half volume is deposited when the former gas is left standing
over mercury or water. It seems therefore to be only very
loosely united to the other constituents.

It is obvious that sesquihydret of phosphorus is a com-
pound of

$1\frac{1}{2}$ atom hydrogen	. .	0·1875
1 atom phosphorus	. .	2·
		2·1875

Its atomic weight is therefore 2·1875. This constitution is
implied by the name *sesquihydret of phosphorus.*

When mixed with chlorine gas it burns spontaneously with
a white flame. According to Davy, 1 volume of sesquihydret
of phosphorus requires 4 volumes of chlorine gas for complete
combustion. 1·5 of these volumes uniting to the hydrogen go to
the formation of muriatic acid. The other 2·5 must combine with
the phosphorus, and form a perchloride of phosphorus which

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[*] Ann. de Chim. et de Phys. xxxi. 128.

would be speedily converted into muriatic acid and phosphoric acid, by decomposing water. So that the products, in this case, are precisely the same as when phosphuretted hydrogen is burnt in chlorine.

According to Davy, water absorbs $\frac{1}{8}$th of its volume of this gas. So that the absorbability of this gas and olefiant gas, by water, is the same.

It is rapidly absorbed by sulphuric acid to a considerable extent; sulphurous acid is speedily given out and phosphorus deposited. Most of the metals decompose this gas when assisted by heat, uniting to the phosphorus, and setting the hydrogen at liberty.*

VIII. No compound of phosphorus and azote has hitherto been formed. When phosphorus is allowed to remain in common air till it ceases to smoke, the azotic gas thus evolved has the property of becoming luminous in the dark, when mixed with oxygen gas or common air. And Berthollet affirms that its volume is increased about $\frac{1}{40}$th part. But this is not a chemical compound of azote and phosphorus. It is merely azotic gas in which a little phosphorus exists in the state of vapour.

Phosphuret of carbon.

IX. Phosphorus has the property likewise of uniting with carbon, and of forming a compound, called *phosphuret of carbon*. Its existence was first recognised by M. Proust. He gave that name to the red substance which remains when new-made charcoal is strained through shamois leather.† It is not improbable that this red substance may frequently contain phosphuret of carbon, especially as the same assertion has been subsequently made by Thenard.‡ But I have never been able to

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* Davy assures us that when sulphur is sublimed in this gas the volume is doubled, and 2 volumes of sulphuretted hydrogen gas are formed. When potassium is heated in it, the volume is also doubled. The potassium combines with phosphorus, and the residual gas is pure hydrogen. These properties do not agree with those of the gas extricated by heating phosphatic acid, or by allowing phosphuretted hydrogen to lose a portion of its phosphorus by exposure. They would indicate a gas composed of

2 volumes hydrogen	. .	0·1388
1 volume phosphorus	. .	1·1111
		1·25

Its specific gravity would be 1·25, and its atomic weight 2·25. It is not at all unlikely that such a gas may also exist. It would be a bihydret of phosphorus.

† Ann. de Chim. xxxiv. 44.   ‡ Ibid. lxxxi. 109.

find any such substance in it.* The experiments of Vogel appear to have been equally unsuccessful.† But I have generally procured it by the following method.

Allow phosphuret of lime to remain in water till it has given out all the phosphuretted hydrogen gas which it is capable of evolving. Then add to the liquid a considerable excess of muriatic acid, agitate for a few moments, and throw the whole upon a filter. Phosphuret of carbon will remain upon the filter. Let it be properly washed and dried.

Phosphuret of carbon thus obtained is a soft powder of a dirty lemon yellow colour, without either taste or smell. When left in the open air it very slowly imbibes moisture, emits the smell of carburetted hydrogen, and acquires an acid taste. Hence it decomposes the water which it absorbs, and its phosphorus is slowly converted into phosphorous acid. It does not melt when heated; nor is it altered, though kept in a temperature higher than that of boiling water. It burns below a red heat, and when heated to redness, gradually gives out its phosphorus. The charcoal remains behind in the state of a black matter, being prevented from burning by a coating of phosphoric acid with which it is covered. When the powder is thrown over the fire in small quantities at a time, it burns in beautiful flashes. It is probably composed of 1 atom phosphorus, and 1 atom carbon, or by weight of

> Phosphorus . . 2
> Carbon . . 0·75

The substance when distilled gives no trace of water.‡

X. Nothing is known respecting the combination of phosphorus with boron or silicon.

SECTION VII.—OF SULPHUR.

Sulphur, distinguished also by the name of brimstone, was known in the earliest ages. Considerable quantities of it are found native, especially in the neighbourhood of volcanoes, and it is procured in abundance by subjecting the mineral called *pyrites* to distillation. The ancients used it in medicine, and its fumes were employed in bleaching wool.§

1. Sulphur is a hard brittle substance, commonly of a greenish Properties.

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* Twice indeed on distilling this substance I obtained a residue of charcoal. But I never could succeed in obtaining the phosphuret in a separate state.

† Ann. de Chim. lxxxv. 225.   ‡ Annals of Philosophy, viii. 157.

§ Pliny, lib. xxxv. c. 15.

yellow colour, without any smell, and of a weak though perceptible taste.

It is a non-conductor of electricity, and of course becomes electric by friction. Its specific gravity I found in a specimen of pure roll sulphur to be 1·977; while that of another specimen was 2·000. Brisson found the specific gravity of native sulphur 2·0332; while Roget and Dumas found it as high as 2·086.*

Sulphur undergoes no change by being allowed to remain exposed to the open air. When thrown into water, it does not melt as common salt does, but falls to the bottom, and remains there unchanged : it is therefore insoluble in water.

2. If a considerable piece of sulphur be exposed to a sudden though gentle heat, by holding it in the hand, for instance, it breaks to pieces with a crackling noise.

When sulphur is heated to the temperature of about 170°, it rises up in the form of a fine powder, which may be easily collected in a proper vessel. This powder is called *flowers of sulphur.*†

When heated to the temperature of about 218° of Fahrenheit's thermometer, it melts and becomes as liquid as water. If this experiment be made in a thin glass vessel, of an egg shape, and having a narrow mouth,‡ the vessel may be placed upon burning coals without much risk of breaking it. The strong heat soon causes the sulphur to boil, and converts it into a brown coloured vapour, which fills the vessel, and issues with considerable force out from its mouth.

Effect of heat. M. Dumas fixes the melting point of sulphur at 226°·5, which I consider as too high. Between the melting point and 252°, it is as liquid as a varnish, and its colour is that of amber. About the temperature of 340° it begins to get thick and assumes a reddish tinge, and if we continue to increase the temperature it becomes so thick that the vessel containing it may be turned upside down without the risk of spilling any of it. Between the temperature of 428° and that of 482° it is thickest of all, and its colour is reddish brown. From 482° to its boiling point, which is not far from 750°, it becomes thinner, but never so thin as it was when below the temperature of 248°, and its reddish brown colour does not alter. If it be

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* Annals of Philosophy (2d series), iii. 392.

† It is only in this state that sulphur is to be found in commerce tolerably pure. *Roll sulphur* usually contains a considerable portion of foreign bodies.

‡ Such vessels are usually called *receivers* or *flasks* by chemists.

suddenly cooled while in the most liquid state, as by throwing it into water, it becomes instantly brittle; but if it was so hot as to be viscid, and be suddenly cooled, it remains quite soft; so that it may be drawn into threads. In the first case it crystallizes, in the second case it does not.* This state of softness is probably connected with the viscidity; which when the cold is suddenly applied, prevents the possibility of the particles arranging themselves in regular order.

3. Sulphur is capable of crystallizing. If it be melted, and, as soon as its surface begins to congeal, the liquid sulphur beneath be poured out, the internal cavity will exhibit long needle-shaped crystals of an octahedral figure. This method of crystallizing sulphur was contrived by Rouelle. If the experiment be made in a glass vessel, or upon a flat plate of iron, the crystals will be perceived beginning to shoot when the temperature sinks to 220°. Sulphur is frequently found native in fine large crystals. The primary form of the crystals is an octahedron, with scalene triangular faces. It consists of two pyramids joined together, base to base. These bases constitute a rhomboid, the longer diagonel of which is to the shorter as 5 to 4.

The perpendicular drawn from the centre of this rhomboid to the edge is to the height of the pyramid as 1 to 3.† Mitcherlich has shown that the form of the crystal is different when sulphur crystallizes in a state of fusion by heat. The primary form is then a doubly oblique four-sided prism.‡

4. Alcohol dissolves a small portion of sulphur. So does sulphuric ether and oils.

II. Sulphur combines in five proportions with oxygen, and forms five compounds, which have received the names of *sulphuric acid, sulphurous acid, hyposulphurous acid, subsulphurous acid,* and *hyposulphuric acid.*

1. When sulphur is heated to the temperature of about 300° in the open air, it takes fire spontaneously, and burns with a pale blue flame, and at the same time emits a great quantity of fumes of a very strong suffocating odour. When set on fire, and then plunged into a jar full of oxygen gas, it burns with a bright violet coloured flame, and at the same time emits a vast quantity of fumes. If the heat be continued long

Compounds with oxygen.

* Dumas; Ann. de Chim. et de Phys. xxxvi. 83.
† Haüy's Mineralogie, iii. 278. ‡ See page 16 of this volume.

enough, the sulphur burns all away without leaving any ashes or residuum.　If the fumes be collected, they are found to consist of sulphurous acid.　By combustion, then, sulphur is converted into acid.　This fact was known several centuries ago; but no intelligible explanation was given of it till the time of Stahl.

According to him, sulphur is a compound of sulphuric acid and phlogiston.　By combustion the phlogiston is driven off, and the acid remains behind.　The experiments by which he endeavoured to establish these opinions were long considered as satisfactory.　But it was observed that sulphur will not burn unless air be present, and that sulphuric acid is heavier than the sulphur from which it was produced.　These facts were incompatible with the hypothesis of Stahl.　Lavoisier first explained them by showing that, during combustion, sulphur unites with the oxygen of the air, and that the acid formed is exactly equal to the weight of the sulphur and oxygen which disappeared.　Hence he concluded that the acid formed is a compound of these two bodies—an opinion which is now universally acceded to.

Sulphurous acid.　2. Sulphurous acid is formed, when sulphur is burnt, either in the open air, or in oxygen gas.　But the best way to procure it in quantities, is to heat a mixture of sulphuric acid and mercury in a small retort, and receive the gaseous product over mercury,　This gas is sulphurous acid.

This acid was first examined by Stahl, who gave it the name of *phlogisticated sulphuric acid.*　Scheele in 1774 pointed out a method of procuring it in quantities.[*]　Dr. Priestley, about the same time, obtained it in the gaseous form, and ascertained many of its properties.[†]　Berthollet examined it in 1782 and 1789.[‡]　Fourcroy and Vauquelin published a detailed set of experiments on it in 1797.[§]　Some experiments on it by me were published in 1803.[||]

Sulphurous acid gas is colourless, and possesses the mechanical properties of common air.　Its smell is exceedingly suffocating and disagreeable, being precisely similar to the smell of burning sulphur.　Its taste is intensely acid and sulphureous.　It converts vegetable blues to red, and then gradually destroys

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[*] Scheele's Memoires de Chymie, i. 43.　　　[†] Priestley on Air, ii. 295.
[‡] Mem. Par. 1782. and Ann. de Chim. ii. 54.
[§] Ann. de Chim. xxiv. 229.　　　[||] Nicholson's Journal, vi. 93.

them. Its specific gravity, according to Davy's experiments, is 2·2293.* According to Berzelius and Dulong, 2·247.† If we suppose it composed of a volume of vapour of sulphur, and a volume of oxygen gas, condensed into one volume, its specific gravity ought to be 2·2222. Now this is confirmed by an experiment made in my laboratory; we found the specific gravity of the gas 2·221.

I ascertained, by experiment, that the quantity of oxygen in sulphurous acid is $\frac{2}{3}$ of that in sulphuric acid.‡ Now we shall see immediately that sulphuric acid is composed of 100 sulphur + 150 oxygen. Hence it follows that sulphurous acid is composed of 100 sulphur + 100 oxygen. There is another experiment which demonstrates, in a very satisfactory manner, the composition of this acid. Sulphuretted hydrogen is a gas which will be described in the subsequent part of this section. It contains its own volume of hydrogen, holding a volume of sulphur in solution. Now a volume of this gas requires $1\frac{1}{2}$ volume of oxygen for complete combustion. The substances formed are water and sulphurous acid. The half volume of the oxygen goes to the formation of water, and combines with the hydrogen. The one volume of oxygen combines with all the sulphur, and forms sulphurous acid. The sulphur, in a volume of sulphuretted hydrogen, is obtained by subtracting the specific gravity of hydrogen gas from that of sulphuretted hydrogen.

Sp. gravity of sulphuretted hydrogen	.	.	1·1805
———————— hydrogen gas	.	.	0·0694
Sulphur in the gas	.	.	1·1111

But the specific gravity of oxygen gas is 1·111. Hence it follows that sulphurous acid is composed of

Sulphur	. .	1·111¹
Oxygen	. .	1·111¹

It is obvious from this that sulphurous acid gas is a compound of

1 volume oxygen gas, ⎱ condensed into 1 volume. Hence
1 volume sulphur vapour, ⎰ the specific gravity of sulphur vapour and oxygen gas are precisely the same.

The atomic weight of sulphur, as will appear immediately, is 2. Now 2 multiplied by 0·5555 must give us the specific gravity of sulphur vapour. And $2 \times 0·5555 = 1·1111$.

* Phil. Trans. 1812, p. 412. † Ann. de Chim. et de Phys. v. 178.
‡ Nicholson's Journal, vi. 95.

3. Sulphuric acid is obtained by burning a mixture of about 7 parts sulphur and 1 part nitre, in large chambers lined with lead. By this combustion, sulphurous acid and deutoxide of azote are formed. The deutoxide absorbs oxygen from the atmosphere, and is converted into nitrous acid. Both the acids are absorbed by water. The nitrous acid gives out part of its oxygen to the sulphurous acid, and converts it into sulphuric acid, and being reduced to the state of deutoxide again flies off, unites to oxygen, is converted into nitrous acid, and absorbed by the water. This process goes on till the whole of the sulphurous acid is converted into sulphuric acid.* The water, thus acidulated, is evaporated in leaden vessels to a certain point. The evaporation is then continued in glass retorts, till the acid acquires the requisite degree of strength. By this evaporation a very considerable portion of the water is driven off. But by this process, sulphuric acid cannot be deprived of the whole of its water.

Sulphuric acid is colourless like water. It has somewhat of a glutinous consistency; is destitute of smell, but has an exceedingly acid taste. It speedily chars animal and vegetable substances when placed in contact with them. It converts vegetable blues to red. Acid of the specific gravity 1·85, boils, according to Mr. Dalton, at the temperature of 620°. The boiling point diminishes with the strength. Acid of the specific gravity 1·780, boils at 435°, and acid of the specific gravity 1·650, at 350°.†

Many experiments have been made to determine the proportion of oxygen contained in sulphuric acid. It is unneces-

sary to state the trials of Berthollet, Trommsdorf, Lavoisier, Chenevix, and Thenard, because they are very inaccurate. Bucholz, Klaproth, Richter, and Berzelius approach much nearer to the truth. Their estimates are as follows:

Bucholz 100 sulphur + 135·3 oxygen.
Klaproth 100   + 138·1
Richter 100   + 138·1
Berzelius 100   + 149·1

The determination of Berzelius is much more exact than any of the others, and is in fact exceedingly near the truth.

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* Clement and Desormes, Ann. de Chim. lix. 329.—Dalton, New System of Chemical Philosophy, ii. 396.—Davy, Elements of Chemical Philosophy, p. 276.

† Dalton's New System of Chemical Philosophy, ii. 404.

I find by a careful set of experiments that the atomic weight of sulphuric acid is exactly 5, and that of sulphurous acid 4. For 4 soda and 6 potash are exactly saturated by 5 of sulphuric acid, and 4 of sulphurous acid. Farther, sulphite of potash may be converted into sulphate of potash by dissolving it in water, and leaving the solution for a sufficient time exposed to the atmosphere. The neutral state of the salt is not altered by this change. Hence it follows that sulphurous and sulphuric acids contain exactly the same weight of sulphur. The difference between their weights is owing to the difference of their oxygen. Now this difference being unity, it is clear that sulphuric acid contains 1 atom more oxygen than sulphurous acid. Farther, if we take 2 grains of sulphur and dissolve them in nitric acid, we will convert them into 5 grains of sulphuric acid. From this, it is obvious that sulphuric acid is composed of

Sulphur	.	.	2
Oxygen	. .	.	3
			—
			5

Sulphurous acid must of course be composed of

Sulphur	.	.	2
Oxygen	.	.	2
			—
			4

Hence it is evident that the atomic weight of sulphur is 2, and that sulphurous acid is a compound of 1 atom sulphur and 2 atoms oxygen; while sulphuric acid is a compound of 1 atom sulphur and 3 atoms oxygen.

Berzelius makes the atom of sulphur 2·01165. This number he founds on analytical experiments; as if it were possible by experiment to determine the millionth part of the matter subjected to analysis. He endeavours also to deduce from Œrsted's experiments on the compressibility of sulphurous acid gas, that it is impossible that sulphurous acid can be a compound of equal weights of sulphur and oxygen. He does not attend to the circumstances of the case, otherwise he would see that these experiments militate against his conclusions. It has been established by satisfactory trials, that when sulphur is burnt in oxygen gas, that gas is changed into sulphurous acid without any alteration in volume. Hence the increase of the specific gravity measures the weight of sulphur combined with the oxygen gas. But says Berzelius the weight of sul-

phurous acid gas is greater than it ought to be, supposing it a compound of equal weights of oxygen and sulphur. The reason assigned by himself accounts for this; it is owing to the easy compressibility of sulphurous acid into a liquid. But I know from actual trial that the specific gravity of sulphurous acid gas may be taken without any condensation whatever, and that then its density is 2·221. That Berzelius's number for the specific gravity of sulphurous acid is not quite correct, is evident from this, that if we subtract from it his own specific gravity of oxygen gas, we obtain 2·0756 for the atom of sulphur, instead of 2·01165 his own atomic weight. For 2·247—1·1026 = 1·1444 and 1·1026 : 1·1444 : : 2 : 2·0756 = atom of sulphur.

Subsulphurous acid.

4. An observation of Mr. Higgins of Dublin, had it been attended to, might have led chemists long ago to infer the existence of *subsulphurous acid*. He found that sulphurous acid has the property of dissolving iron without the evolution of any gas.* But Mr. Higgins did not determine the nature of the solution of iron thus obtained. This was done in 1789 by M. Berthollet. He showed that a greater proportion of sulphur was present in the solution than sulphurous acid contains. The reason was, he observed, that the iron was oxydized at the expense of the sulphurous acid, a portion of which giving out its oxygen to the iron is converted into sulphur. This sulphur combines with the sulphite of iron formed, and constitutes a peculiar kind of salts to which the name of *sulphuretted sulphites* was applied by the French chemists.† Some other of these salts were described by Berthollet and by Fourcroy, and Vauquelin. And some new facts concerning them were noticed by Gay-Lussac in 1813.‡ It was in the year 1815, that I first paid minute attention to the solution of iron in sulphurous acid. I concluded from the phenomena, that the acid gave out half its oxygen to the iron, and converted it into protoxide of iron. I found the salt formed a neutral salt; but when I attempted to separate the acid it was immediately decomposed into sulphurous acid and sulphur. I drew as an inference that the salt contained a peculiar acid of sulphur, consisting of sulphurous acid deprived of half its oxygen, and therefore composed of one atom of sulphur + one atom of oxygen. To this new acid I gave the name of *hyposulphurous*

* Higgin's Comparative View, p. 49.   † Ann. de Chim. ii, 58.
‡ Ibid. lxxxv. 199.

acid, and I announced the existence of this acid in the fifth edition of my System of Chemistry, published in 1817. In that edition the existence of the acid is stated, and the salts previously described in books by the name of *sulphuretted sul-phites* are called *hyposulphites.* * But the discovery of a new acid containing still less oxygen than this, by Mr. Herschell, makes it expedient to give to the acid formed, by dissolving iron or zinc in sulphurous acid, the name of *subsulphurous acid.* If the sulphurous acid be pure, zinc dissolves in it without any effervescence whatever. When the salt is decomposed, the subsulphurous acid is resolved into sulphurous acid and sulphur. No accurate experiments have hitherto been made on the subject; but there seems no reason to doubt from the phenomena, that during the solution of the zinc, the sulphurous acid gives out half its oxygen to oxydize the zinc. The subsulphurous acid must then be a compound of

1 atom sulphur	.	.	2
1 atom oxygen	.	.	1
			3

and its atomic weight must be 3. It seems incapable of existing except in combination with a base. When insulated half the sulphur separates, and sulphurous acid remains.

5. The acid discovered by Mr. Herschell, and to which he gave the name of hyposulphurous acid, seems equally incapable of existing except in combination with a base. When sulphuric acid in a slight excess is poured into a dilute solution of hyposulphite of strontian, the whole strontian is thrown down, and the filtered liquid consists chiefly of a solution of hyposulphurous acid in water. This liquid is transparent and colourless, is destitute of smell, and has an acid, astringent, and very bitter taste. On standing a few hours, the acid undergoes spontaneous decomposition, the liquid becomes milky, sulphur is deposited, and sulphurous acid remains in solution.

During a set of experiments on chromium, in which I was engaged about five years ago, I found that when a current of sulphuretted hydrogen gas was passed through a solution of

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* I have been thus minute in my account of my ideas respecting this acid, because I observe that Gay-Lussac lays claim to the discovery of it. But . I am not aware of the least hint at the existence of any such acid, either in the writings of Gay-Lussac, or of any other person previous to the publication of the fifth edition of my System of Chemistry.

† Edin. Philos. Journal, i. 8 and 396, and ii. 154.

chromate of potath, the chromic acid is reduced and precipitated in the state of hydro-sulphuret of chromium, and the residual liquid contains a solution of hyposulphite of potash. This fact induced me to make a set of experiments on the composition of hyposulphurous acid, which I was fortunately enabled to do by means of a salt, which made its appearance in the soda leys of Mr. Tennant of Glasgow, during the very warm summer of 1825.

This salt had a hot, bitter, and sulphureous taste, and was crystallized in regular octahedrons. It gradually deliquesced and acted very strongly as an alkali. It was composed of

1 atom bisulphuretted hydrogen　.　.	4·125
1 atom soda　.　.　.　.　.	4
6 atoms water　.　.　.　.　.	6·75
	————
	14·875

The bisulphuretted hydrogen (as its name implies) is a compound of 2 atoms sulphur and 1 atom hydrogen. If we dissolve this salt in water and add to the solution sulphurous acid as long as the acid continues to lose its smell, one half of the sulphur which it contains is thrown down, and the salt is converted into hyposulphite of potash, which may be obtained in large flat four-sided prisms terminated by a bihedral summit. When analyzed its constituents were found to be

1 atom hyposulphurous acid　.　.	5
1 atom soda　.　.　.　.　.	4
4 atoms water　.　.　.　.　.	4·5
	————
	13·5

It is obvious that the hyposulphurous acid is a compound of 2 atoms sulphur and one atom oxygen. For it is formed by adding 4 sulphurous acid to 14·875 of the hydrosulphuret of soda. 2 sulphur precipitate. Consequently 4 sulphur must remain in solution. One-half of the oxygen in the 4 sulphurous acid must have combined with the 0·125 hydrogen united to the sulphur in the bisulphuretted hydrogen. Hence there remains 1 oxygen to combine with 4 sulphur, which must be the constitution of hyposulphurous acid.* I verified this result by analyzing the hyposulphites of barytes and lead, prepared by Mr. Herschell's process. Hyposulphurous acid then is a compound of

* See Phil. Trans. 1827, p. 165.

2 atoms sulphur	.	.	4
1 atom oxygen	.	.	1
			—
			5

So that its atomic weight is the same as that of sulphuric acid.

6. Another acid compound of oxygen and sulphur was discovered by Messrs. Gay-Lussac and Welter, and called by them *hyposulphuric acid*.

Welter caused a current of the sulphurous acid gas to pass through black oxide of manganese suspended in water. By this process he formed a neutral salt, which he requested Gay-Lussac to examine. It was during their mutual examination of this salt that the new acid was discovered. The solution thus formed consists of a mixture of neutral sulphate and hyposulphate of manganese. Pour into this solution barytes water. The whole of the sulphate of manganese is thrown down, while the hyposulphate is converted into hyposulphate of barytes, which remains in solution. •A current of carbonic acid throws down any excess of barytes that may have been added; then evaporate the liquid, and the hyposulphate of barytes will be obtained in crystals. Dissolve these crystals in water, and precipitate the barytes by means of sulphuric acid, taking care not to add any excess of that acid. The liquid now consists of water, holding hyposulphuric acid in solution.• This acid is colourless and destitute of smell. It may be concentrated till its specific gravity is 1·347, but no higher. It then begins to be decomposed by heat, sulphurous·acid flies off, and sulphuric acid remains behind.* It was found that it could be completely resolved into sulphurous and sulphuric acids in the proportion of 4 parts of the former and 5 parts of the latter. It is therefore composed of an integrant particle of sulphuric acid united to an integrant particle of sulphurous acid. Its constituents therefore are

2 atoms sulphur	.	.	.	4
5 atoms oxygen	.	.	.	5
				—
				9

And its atomic weight is 9. It is similar in its constitution to phosphoric acid. It is a very curious fact that sulphuric and sulphurous acids should be capable of uniting together, and of

Hyposulphu-ric acid.

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forming a new compound acid whose saturating power is not greater than that of either of its constituents.

Thus we know at present no fewer than five compounds of oxygen and sulphur, all of which are acids. Their names, constituents, and atomic weights, are as follows.

	Sulphur.	Oxygen.	Atomic weight.
1. Hyposulphurous acid	2 atoms	+ 1 atom	. . 5
2. Subsulphurous acid	1	+ 1	. . 3
3. Sulphurous acid	1	+ 2	. . 4
4. Sulphuric acid	1	+ 3	. . 5
5. Hyposulphuric acid	2	+ 5	. . 9

Chlorides of sulphur.   III. Sulphur combines readily with chlorine, and forms a liquid compound which has received the name of *chloride of sulphur*. This substance was first described by me in 1803.* It was examined by M. Berthollet, junior, in 1807,† and by Mr. Bucholz in 1810.‡

It is easily obtained by passing a current of chlorine gas through flowers of sulphur. It may be obtained also, as Davy first observed, by heating sulphur in a dry glass vessel filled with chlorine gas.

It is a liquid of a brownish red colour when seen by reflected light; but appears yellowish green when seen by transmitted light. Its smell is strong and somewhat similar to that of sea plants, or which we perceive when walking along the sea-shore. The eyes when exposed to it are filled with tears and acquire the same painful feeling as when exposed to wood or peat smoke. The taste is acid, hot and bitter, affecting the throat with a painful tickling. It does not change the colour of dry litmus paper; but if the paper be moist it immediately becomes red. I found the specific gravity 1·6789. But Berthollet found it 1·7 and Bucholz 1·699. It readily dissolves sulphur, and acquires a brown colour. It dissolves phosphorus with facility. The solution has a fine amber colour and is permanent. Chloride of sulphur soon flies off, leaving crystals of sulphur if it contains that substance in solution. When dropped into water it is decomposed, sulphur being evolved. When dropped into nitric acid a violent effervescence is produced, and sulphuric acid formed.

According to Davy 10 grains of sulphur absorb 30 cubic inches or 22·3589 grains of chlorine. Hence it is composed of

* Nicholson's Journal, vi. p. 104.   † Mem. de Arcueil, i. 161.
‡ Gehlen's Journal, für die Chemie, Physik und Mineralogie, ix. 172.

Sulphur   .   .   2
Chlorine   .   .   4·672

It is evident from this that it is a compound of 1 atom sulphur
and 1 atom chlorine. Hence its atomic weight is 6·5.

I analyzed a specimen of chloride of sulphur of the specific
gravity 1·7, and found it a compound of

1 atom chlorine   .   .   4·5
2 atoms sulphur   .   .   4·
                           ———
                           8·5

It was therefore a dichloride, and its atomic weight was 8·5.

Thus there are two chlorides of sulphur. The chloride,
composed of an atom of each constituent, has a red colour and
a specific gravity of only 1·628. It may be made by continu-
ing the current of chlorine gas till the chloride refuses to
absorb any more. Or by mixing together 100 parts of corro-
sive sublimate and 12 parts of sulphur, and distilling with a
moderate heat. The dichloride may be made by saturating
the chloride with sulphur till it refuses to take up any more.
Its colour is brown, its specific gravity greater, and when
evaporated it leaves one half of its sulphur behind.

No attempt has been hitherto made to determine the specific
gravity of the vapour of chloride of sulphur. But as it is a com-
pound obviously of 1 volume chlorine gas and 1 volume vapour
of sulphur probably condensed into 1 volume, its specific gravity
must be 3·6111. If dichloride be a compound of two volumes
of sulphur vapour and 1 volume of chlorine gas condensed into
1 volume, the specific gravity of its vapour must be 4·7222.

Dumas subjected the chloride of sulphur to analysis. His
method was to pass the vapour through hot turnings of iron.
Chloride and sulphuret of iron were formed. The chlorine
was thrown down and estimated by means of nitrate of silver.
The sulphur was driven off in the state of sulphuretted hydro-
gen and united with lead. He obtained

Sulphur   .   .   3   or 2
Chlorine   .   .   · 7·167   4·778*

This corroborates the analysis of Davy. Both the chloride of
Davy and of Dumas seems to have contained a slight excess of
chlorine.

It appears from the experiments of Bischoff, that dichloride

of sulphur yields beautiful crystals of sulphur.   The shape of
the crystal is the usual rhomboidal octahedron.*

    IV. Bromide of sulphur is easily formed by pouring bromine
on flowers of sulphur.   The sulphur is converted into an oily-
looking liquid having a much deeper red colour than chloride
of sulphur.   Like that compound it exhales vapours when left
in the open air, and its smell is somewhat similar.   It slightly
reddens litmus paper, unless water be present when the action
is strong.   Cold water has but little action on it; but at a
boiling temperature a slight detonation takes place, hydro-
bromic acid is formed together with sulphuric acid and sulphu-
retted hydrogen.   Chlorine decomposes this bromide.   Bromine
is driven off and chloride of sulphur formed.†   It is obvious
from this that bromide of sulphur is a compound of

            1 atom bromine   .   .   10
            1 atom sulphur   .   .   2
                                    —
                                12

and that its atomic weight is 12.

    V. Sulphur has the property of combining with iodine, and
of forming a compound which has been called *iodide of sulphur.*
It was first described by Gay-Lussac.‡

    It is easily formed by mixing together the two constituents
in a glass tube and exposing them to a heat sufficient to melt
the sulphur.   This iodide is grayish black, and has a radiated
structure like that of sulphuret of antimony.   When distilled
with water, iodine is disengaged.   When heated sufficiently
to produce fusion a portion of the iodine is likewise disengaged.

    This iodide has not hitherto been analyzed.   But from the
observation of M. Henry, that the best way of procuring it in
a crystallized state, is to mix 1 part of sulphur with 4 of iodine,
it is obvious that it is a diodide of sulphur or a compound of

            1 atom iodine   .   .   15·75
            2 atoms sulphur   .   .   4
                                    —
                             19·75

Doubtless there exists a simple iodide of sulphur, which from
analogy is probably a liquid.

    VI. It would appear from an experiment of Sir H. Davy

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* Schweigger's Jahrbuch, vi. 270.
† Ballard; Ann. de Chim. et de Phys. xxxii. 375.
‡ Ann. de Chim. xci. 22.

that sulphur may be combined with fluorine. He mixed sulphur with fluate of lead (fluoride of lead), and distilled in a platinum vessel. Sulphuret of lead was formed and a fluid volatilized, which in all probability was a fluoride of sulphur. But Davy did not examine the properties of this remarkable fluid.

VII. Sulphur has the property of combining with hydrogen, and of forming a gaseous compound which has received the name of sulphuretted hydrogen gas. Gay-Lussac has given it the name of *hydrosulphuric acid*, which has been pretty generally adopted.

That such a gas existed, and that it was inflammable, had been observed by Rouelle ;* but its properties and composition were first investigated by Scheele in 1777, who must therefore be considered as the real discoverer of it.† Bergman, in 1778, detailed its properties at greater length,‡ having examined it probably after reading the experiments of Scheele. In 1786, Mr. Kirwan published a copious and ingenious set of experiments on it.§ The Dutch chemists examined it in 1792,‖ and in 1794 Berthollet, with his usual sagacity, still further developed its properties;¶ and since that time several important facts respecting it have been ascertained by Proust and Thenard.

Berzelius published an elaborate analysis of it in 1807 ;** and Gay-Lussac, Thenard,†† and Sir H. Davy,‡‡ have ascertained several of its properties with precision.

It may be obtained by pouring sulphuric or muriatic acid upon several metallic sulphurets. Sulphuret of antimony yields it very pure ; but the muriatic acid must be concentrated, and the action of the acid must be assisted by heat. Sulphuret of iron furnishes it very readily, and may be formed by plunging red-hot iron into sulphur, or by heating together iron filings and sulphur in a covered crucible. Gay-Lussac proposed a very convenient method of procuring this gas. It consists in mixing together 2 parts of sulphur and 4·5 parts of iron filings

* Macquer's Dict. i. 520.
† Scheele on Air and Fire, p. 186, Engl. Trans.
‡ See his Treatise on Hot Mineral Waters, Opus. i. 233, and Engl. Trans. i. 290.
§ Phil. Trans. 1786, p. 118.
‖ Ann. de Chim. xiv. 294.   ¶ Ibid. xxv. 233.
** Afhandlingar i Fysik, Kemi och Mineralogi, ii. 78.
†† Recherches Physico-chimiques, i. 191.
‡‡ Phil. Trans. 1812, p. 412.

in a retort with a considerable quantity of water, and heating the whole nearly to the boiling temperature. The sulphur and iron filings act upon each other, considerable heat is evolved, and a black matter formed which yields a great deal of sulphuretted hydrogen when an acid is poured into it. This mixture must not be prepared long before it is used; and it will not yield pure sulphuretted hydrogen gas unless the iron filings employed be clean and very small. If they be large the interior will remain in the state of iron, and hydrogen gas will be evolved when sulphuric acid is poured into the mixture.

An economical method of procuring sulphuretted hydrogen has been proposed by M. Berthier, which seems entitled to the attention of chemists. His method is this, reduce sulphate of lime to an impalpable powder, and mix it if anhydrous with the 5th part of its weight of charcoal powder; but if in the state of an hidrate with about ⅟₇th. Put the mixture into a crucible, and raise its temperature very slowly to whiteness, keeping it in a white heat for nearly an hour.* It is now converted into sulphuret of lime, but it still retains its pulverulent state, and may be kept in a close vessel for use. When muriatic acid is poured upon this matter, it gives out sulphuretted hydrogen gas very rapidly, and to the amount of 46·8 per cent.

Sulphuretted hydrogen gas is colourless, and possesses the mechanical properties of air. It has a strong fetid smell, not unlike that of rotten eggs. It does not support combustion, nor can animals breathe it without suffocation. Its specific gravity, according to the experiments of Gay-Lussac and Thenard, is 1·1912.† According to Sir H. Davy, it is 1·1967. I found its specific gravity 1·1788. It will appear immediately that the true specific gravity is 1·1805.

Its refracting power, according to the experiments of Dulong, is 2·187, that of air being unity.‡

Mr. Faraday succeeded in reducing this gas to the state of a liquid. His method was to put sulphuret of iron and muriatic acid into a bent tube shut at one end, and so contrived, that the two bodies did not come in contact till the open end of the tube was sealed hermetically. The muriatic acid was then brought in contact with the sulphuret of iron, while the other end of the tube was surrounded by a mixture of snow and salt. By the united action of the pressure and cold the

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* Ann. de Chim. et de Phys. xxiv. 273.
† Recherches Physico-chimiques, i. 191.
‡ Ann. de Chim. et de Phys. xxxi. 167.

sulphuretted hydrogen evolved condensed into a liquid. This liquid was transparent and colourless and exceedingly mobile, so that ether when compared with it appeared somewhat viscid. Its specific gravity was about 0·9, and at the temperature of 50°, it required a pressure amounting to 17 atmospheres to keep it in a state of fluidity.*

This gas is rapidly absorbed by water. According to Dr. Henry, 100 cubic inches of this liquid absorb, at the temperature of 50°, 108 cubic inches of sulphuretted hydrogen.† But the gas must have been impure. Theodore de Saussure found that 100 cubic inches of water absorb 253 cubic inches of pure sulphuretted hydrogen gas.‡ Gay-Lussac found that water absorbed at least three times its volume of this gas. I prepared a quantity of very pure gas by means of sulphuret of antimony, and left it in a glass jar standing over mercury with a measured volume of water in contact with it. The result was that in 24 hours the water absorbed 3·66 times its volume of the gas. Alcohol of the specific gravity 0·84 absorbs, according to Saussure, 6·06 times its volume of gas. Mr. Higgins has shown likewise that it dissolves in ether. The water thus impregnated is colourless, but it has the smell of the gas, and a sweetish nauseous taste. It converts vegetable blue colours to red, and has many other properties analogous to those of acids. When the liquid is exposed to the open air the gas gradually makes its escape.

When sulphuretted hydrogen gas is set on fire, it burns with a bluish red flame, and at the same time deposits a quantity of sulphur. When the electric spark is passed through it, sulphur is deposited, but its bulk is scarcely altered.§ It deposits sulphur also when agitated with nitric acid, or when that acid is dropped into water impregnated with it.‖ If into a small phial filled with this gas, we let fall a few drops of nitric acid, and then shut the mouth of the phial with the finger, so much heat is evolved, that the gas catches fire and burns with a beautiful flame.

When mixed with common air it burns rapidly, but does not explode. When mixed with its own bulk of oxygen gas, and fired with electricity, an explosion is produced, and no sulphur deposited; but the inside of the glass is moistened with water. For complete combustion it requires 1½ volume

* Phil. Trans. 1826, p. 544.   † Ibid. 1803, p. 274.
‡ Annals of Philosophy. vi. 340.   § Austin, Phil. Trans. 1788, p. 385.
‖ Scheele, on Air and Fire, p. 190.

of oxygen gas. It is converted into water and sulphurous acid. The half volume of the oxygen goes to the formation of water, and the whole volume to the formation of sulphurous acid.

When electrical sparks are made to pass for a long time through this gas the whole sulphur is deposited, and the bulk of the gas is not altered; but it is converted into pure hydrogen gas. When sulphur is strongly heated in hydrogen gas a quantity of sulphuretted hydrogen gas is formed; but the bulk of the gas is not altered. It is obvious from all these facts, that it consists of 1 volume hydrogen gas and 1 volume sulphur vapour united together and condensed into 1 volume. To obtain its specific gravity, therefore, we have only to add together the known specific gravities of these two bodies as already determined.

Sp. gr. of hydrogen gas	. .	0·0694
———— sulphur vapour	. .	1·1111
		1·1805

Thus its specific gravity must be 1·1805, as already stated. This is only a very little heavier than I obtained by experiment.

Composition.   Its constituents then are

1 atom hydrogen	. .	0·125
1 atom sulphur	. .	2·
		2·125

and its atomic weight is 2·125.

Hydrosul-
phurous acid.   2. When three volumes of sulphuretted hydrogen gas, and two volumes of sulphurous acid gas, both dry, are mixed together over mercury, they unite together, and are condensed into a solid body, which adheres firmly to the sides of the vessel. To this compound, which possesses acid properties, the name of *hydrosulphurous acid* may be applied.

The action of these two gases on each other was first observed by Mr. Kirwan.* It was noticed by succeeding writers, but never accurately investigated till I made a set of experiments on the subject in the autumn of 1818. It had been the general opinion that the two gases mutually decomposed each other, and that the products were water and sulphur. If this opinion had been well founded, it is obvious that they would condense each other when mixed in the proportion of two volumes sulphuretted hydrogen, and one volume of sul-

* Phil. Trans. 1786, p. 118.

phurous acid. For (substituting atoms for volumes, which may be done without any mistake) we have

	Atoms.		Atoms.
2 atoms sulphuretted hydrogen, composed of	2 sul.	+	2 hyd.
1 atom sulphurous acid composed of	1	+	2 oxy.

So that the two gases may be resolved into three atoms sulphur weighing 6, and 2 atoms water weighing 2·25.

But as the two gases really combine in the proportions of three volumes sulphuretted hydrogen and two volumes sulphurous acid, it is obvious that they cannot be resolved into sulphur and water, without a residue of oxygen gas amounting to ¼th the bulk of the whole sulphurous acid gas employed. Now when the gases are mixed in the requisite proportions, and in a state of sufficient purity, there is no gaseous residue whatever.

Hydrosulphurous acid is a solid body having an orange yellow colour. Its taste is acid and hot, and it leaves an impression in the mouth which continues for a considerable time. When dry it produces no change upon the colour of litmus paper; but if we moisten the paper ever so little, it tinges it red. Water, alcohol, nitric acid, and sulphuric acid, decompose it, and disengage sulphur. When this substance is agitated in barytes water, no immediate precipitate appears; a sufficient proof that it contains neither sulphurous nor sulphuric acid. It requires a greater heat to produce fusion than sulphur: if the heat be continued, an effervescence takes place, and a quantity of pure sulphur remains behind. I could not succeed in uniting it with bases in the dry way, and whenever moisture is present, this substance is always decomposed. From the constituents employed to form it, we see that hydro-sulphurous acid is composed of

Properties.

Composition.

5 atoms sulphur	.	.	= 10
4 atoms oxygen	.	.	= 4
3 atoms hydrogen	.	.	= 0·375

14·375

So that an integrant particle of it weighs 14·375.*

Or we may consider it as a compound of

3 atoms sulphuretted hydrogen	6·375
2 atoms sulphurous acid	8

14·375

* Annals of Philosophy, xii. 441.

The atomic weight is the same; but when we view these compound bodies as uniting like simple bodies, the subject is rendered more simple and more easily understood.

Bisulphuret of hydrogen.

3. Another compound of sulphur and hydrogen was discovered by Scheele,* and afterwards more particularly examined by Berthollet.† I was led accidentally to analyze it during a set of experiments on chromium in 1825. From its composition it has been called *bisulphuret of hydrogen.*

The best way of preparing it, is to fuse the carbonate of potash in a covered crucible with a considerable excess of sulphur. By this we obtain a sulphuret of potassium containing several atoms of sulphur united to 1 atom of potassium. A concentrated solution of this sulphuret, is to be poured by little and little into dilute muriatic acid, taking care to mix the two liquids well together after every addition. A yellow oily-looking liquid is formed, which collects at the bottom of the vessel, and is transparent, if the process has been conducted successfully. This liquid is the bisulphuret of hydrogen. It cannot be kept; for it undergoes spontaneous decomposition even in well closed vessels; being converted into sulphur and sulphuretted hydrogen. When it is exposed to the air, a quantity of sulphuretted hydrogen gas escapes, and a yellow semi-transparent mass remains adhesive like turpentine, which in a few days solidifies into sulphur.

It is curious that this liquid is formed, and longest preserved in an acid, and that it is immediately destroyed by an alkali. Yet it has the same acid properties as sulphuretted hydrogen. I showed that it constitutes the acid of the octahedral crystals which have been hitherto considered as hydrosulphuret of soda, and that it is a compound of

2 atoms sulphur	.	.	4
1 atom hydrogen	.	.	0·125
			4·125

Its atomic weight consequently is 4·125.‡

Bisulphuret of carbon.

VIII. Sulphur has the property of combining with carbon, and of forming a very remarkable compound, distinguished by the name of bisulphuret of carbon.

History.

The phenomena which take place when sulphur is brought in contact with red-hot charcoal were first observed by Messrs.

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* On Fire, p. 192.　　　† Ann. de Chim. xxv. 247.
‡ Phil. Trans. 1827, p. 165.

Clement and Desormes, during a set of experiments on charcoal. The process which they followed was this : fill a porcelain tube with charcoal, and make it pass through a furnace in such a way that one end shall be considerably elevated above the other. To the lower extremity lute a wide glass tube, of such a length and shape that its end can be plunged to the bottom of a bottle of water. To the elevated extremity lute another wide glass tube filled with small bits of sulphur, and secured at the further end, so that the sulphur may be pushed forward by means of a wire, without allowing the inside of the tube to communicate with the external air. Heat the porcelain tube, and consequently the charcoal which it contains, to redness, and continue the heat till air-bubbles cease to come from the charcoal; then push the sulphur slowly, and piece after piece, into the porcelain tube. A substance passes through the glass tube, and condenses under the water of the bottle into a liquid.*

This liquid was obtained by Lampadius in 1796, while distilling a mixture of pyrites and charcoal, and described by him under the name of *alcohol of sulphur*.† From a later and more detailed set of experiments on it, he drew, as a conclusion, that it is a compound of sulphur and hydrogen.‡ But Clement and Desormes considered it as a compound of sulphur and charcoal ; and inform us, that when it is exposed to evaporate in open vessels a portion of charcoal remains behind. Berthollet Junior, who made some experiments on it, adopted the opinion of Lampadius.§ But the subject was resumed by Cluzel,|| who published an elaborate set of experiments on it in 1812. Berthollet, Thenard, and Vauquelin, who were appointed by the French Institute to examine Cluzel's paper, repeated some of his experiments, and drew, as a conclusion, that the liquid in question is a compound of about 15 carbon and 85 sulphur.¶ Soon after a very complete set of experiments on it were published by Professor Berzelius and Dr. Marcet.** Their results almost exactly agreed with those of the French chemists, and leave no doubt that this liquid is a compound of sulphur and carbon, and that it contains no other ingredient.

Bisulphuret of carbon, when prepared by the process of Clement and Desormes, has at first a yellow colour, owing to

* Ann. de Chim. xlii. 136.
‡ Gehlen's Jour. ii. 192.
|| Ann. de Chim. lxxxiv. 72, 113.
** Phil. Trans. 1813. p. 171.

† Crell's Annals, 1796, ii. 136.
§ Mem. d'Arcueil, i. 304.
¶ Ibid. lxxxiii. 252.

an excess of sulphur which it contains. But when rectified, by being distilled in a retort at a temperature not exceeding 110°, it is obtained in a state of purity.

Properties.

Bisulphuret of carbon is a liquid as transparent and colourless as water. Its taste is acid, pungent, and somewhat aromatic. Its smell is nauseous and fetid, though quite peculiar. Its specific gravity, according to Berzelius and Marcet, is 1·272,[*] according to Cluzel 1·263,[†] the specific gravity of water being 1. Its expansive force at the temperature of 63·5° is equal to a pressure of 7·36 inches of mercury. So that air, to which it is admitted at that temperature, will be dilated by about $\frac{1}{4}$ of its volume.[‡] It boils briskly at a temperature between 105° and 110°. It does not congeal when cooled down to — 60°. It is one of the most volatile liquids known, and produces a greater degree of cold, by its evaporation, than any other substance. The bulb of a thermometer being enveloped in fine lint, dipped in this liquid, and suspended in the air, sinks from 60° to about zero. If it be introduced under the receiver of an air-pump, and the receiver rapidly exhausted, the thermometer will sink to — 82° in less than two minutes.[§]

Bisulphuret of carbon takes fire in the open air, at a temperature scarcely exceeding that at which mercury boils. It burns with a blue flame, giving out the smell of sulphurous acid. Its vapour detonates when mixed with oxygen gas, and an electric spark is passed through it. The products are sulphurous acid and carbonic acid, and carbonic oxide, if the oxygen be in small proportion; but if six or seven times the bulk of the vapour, the whole of the carbon is converted into carbonic acid.

Bisulphuret of carbon is scarcely soluble in water, but alcohol and ether dissolve it readily. Ether is capable of taking up three times its bulk of this liquid without becoming turbid. It readily unites with chloride of azote, and prevents that liquid from detonating, when it comes in contact with oils or phosphorus.[||]

Composition.

When passed through red-hot copper, it combines with that metal, forming a carbosulphuret of metal. By this method, Berthollet, Thenard, and Vauquelin, succeeded in ascertaining its composition. When passed very slowly through red oxide

* Phil. Trans. 1813, p. 175.   † Ann. de Chim. lxxxiv. 83.
‡ Berzelius and Marcet, Phil. Trans. 1813, p. 175.
§ Marcet, Phil. Trans. 1813, p. 252.
|| Berzelius and Marcet, Phil. Trans. 1813, p. 175.

of iron, it is also completely decomposed, and converted partly into sulphuret of iron, and partly into sulphurous acid and carbonic acid gases. By this process, Berzelius succeeded in decomposing it, and ascertained it to be a compound of

Sulphur	.	84·83
Carbon	.	15·17

This result almost coincides with that of the French chemists. Now we have found that an atom of sulphur weighs 2 and an atom of carbon 0·75. On the supposition that sulphuret of carbon is a compound of 2 atoms sulphur, and 1 atom carbon, its constituents would be

Sulphur	4	.	84·21
Carbon	0·75	.	15·79

But these numbers approach so nearly to Berzelius' analysis, that we may safely consider them as exact.

2. There seems likewise to be a solid combination of sulphur and carbon, but its properties have not been examined. Gunpowder is made by triturating together saltpetre, charcoal, and sulphur, so as to make as intimate a mixture as possible. From gunpowder it is easy by means of hot water to wash out all the saltpetre. A black matter remains, which is a compound of sulphur and charcoal, so intimate that the sulphur cannot be separated by sublimation. This seems to be a compound of carbon and sulphur in the proportion of about 5 atoms carbon to 1 atom sulphur; but its nature has not been particularly observed by modern chemists. A similar compound seems to be formed when bisulphuret of carbon is made by the process of Clement and Desormes. When the charcoal remaining after this process is heated with saltpetre, both sulphuric and carbonic acids are formed.

Solid sulphuret of carbon.

3. From an experiment of Scheele, which has not been attended to by modern chemists, it seems not unlikely that there exists also a gaseous compound of sulphur and carbon. He mixed together sulphuret of potassium, and well burnt and pounded charcoal, and distilled the mixture in a retort. A gas was obtained which had the smell of sulphuretted hydrogen; but which was not absorbed by water, and did not possess acid properties. This gas is inflammable, and when burnt the products are carbonic acid gas and sulphurous acid. Chlorine decomposes it instantly, and a portion of sulphur is deposited.* This gas deserves to be more particularly examined.

Gaseous sulphuret of carbon.

* Berzelius' Chemistry, i. 352.

Professor Zeise of Copenhagen has shown that bisulphuret of carbon is capable of forming a new acid, to which the name *hydro-carbosulphuric acid* has been given. I reserve the account of it to a subsequent part of this work.

Sulphuret of boron.

IX. When boron is heated to whiteness in the vapour of sulphur it takes fire and burns with a red flame. The sulphuret formed is white and opaque. If this sulphuret be kept red-hot till the vapour of sulphur with which it is surrounded be condensed on the colder parts of the apparatus, it dissolves in water with the violent evolution of sulphuretted hydrogen gas, and a clear liquid is obtained holding boracic acid in solution. From this it would appear that the sulphuret is a compound of

1 atom sulphur	.	.	2
1 atom boron	.	.	1
			—
			3

The sulphuret of boron, on the contrary, which is withdrawn from the fire as soon as the combustion is at an end, when dissolved in water, not only gives out abundance of sulphuretted hydrogen and forms boracic acid, but deposites also a quantity of sulphur. It must therefore be either a sesquisulphuret or bisulphuret of boron.*

Sulphuret of silicon.

X. When silicon is heated in the vapour of sulphur it catches fire and burns with a red coloured flame. The product is a white coloured earthy looking matter, which may be preserved unaltered in a dry atmosphere. In a red heat it is slowly decomposed, sulphurous acid being given out and silica remaining. The same decomposition takes place in a moist atmosphere. When put into water it is decomposed with great rapidity, dissolving completely with a great disengagement of sulphuretted hydrogen gas. The silicic acid formed is very soluble in water, so that if the quantity of water be small the whole assumes the form of a jelly. It is completely resolved into sulphuretted hydrogen and silica. Hence the sulphuret of silicon is a compound of

1 atom sulphur	.	.	2
1 atom silicon	.	.	1
			—
			3†

Thus both in its constitution and properties it is very analogous to the sulphuret of boron.

* Berzelius; Annals of Philosophy (2d series), x. 129.
† Ibid. 119.

XI. Sulphur and phosphorus readily combine with each other, as was first ascertained by Margraaf.* Pelletier afterwards examined the combination with care.† Some curious observations were published on the formation of this compound by Mr. Accum;‡ and soon after the circumstances under which it takes place were explained with precision by Dr. Briggs.§

All that is necessary is to mix the two substances together, and apply a degree of heat sufficient to melt them, as Pelletier first observed. The compound has a yellowish white colour, and a crystallized appearance.‖ The combination may be obtained by heating the mixture in a glass tube, having its mouth properly secured from the air. The sulphuret of phosphorus, thus prepared, is more combustible than phosphorus. If it be set on fire by means of a hot wire, allowed to burn for a little, and then extinguished by excluding the air, the phosphorus, and perhaps the sulphur, seem to be oxidized, and the mixture acquires the property of taking fire spontaneously as soon as it comes in contact with air.¶

The combination may be procured also by putting the two bodies into a retort, or flask, filled with water, and applying heat cautiously and slowly. They combine together gradually as soon as the phosphorus is melted. It is necessary to apply the heat cautiously, because the sulphuret of phosphorus has the property of decomposing water, as had been observed by Margraaf, and ascertained by Pelletier. The rate of decomposition increases very rapidly with the temperature, a portion of the two combustibles being converted into acids by uniting to the oxygen: the hydrogen at the moment of its evolution unites with sulphur and phosphorus, and forms sulphuretted and phosphuretted hydrogen gases. This evolution, at the boiling temperature, is so rapid as to occasion violent explosions.

The sulphuret of phosphorus may be distilled over without decomposition. Indeed it was by distillation that Margraaf first obtained it. Sulphur and phosphorus, by combining, acquire a considerable tendency to liquidity; and this tendency is a maximum when the two bodies are combined in equal proportions. The following table exhibits the result of Pelletier's experiments on the temperatures at which the compound becomes solid when the substances are united in various proportions.**

* Opusc. i. 11.   † Jour. de Phys. xxxv. 382.   ‡ Nicolson, vi.
§ Ibid. vii. 58.   ‖ Briggs, Nicholson, vii. 58.
¶ Briggs, Nicholson, vii. 58.   ** Ann. de Chim. iv. 10.

8	Phosphorus	} congeals at 77°
1	Sulphur	
8	Phosphorus	} . . . at 59°
2	Sulphur	
8	Phosphorus	} . . . at 50°
4	Sulphur	
8	Phosphrous	} . . . at 41°
8	Sulphur	
4	Phosphorus	} . . . at 54·5°
8	Sulphur	
$2\frac{2}{5}$	Phosphorus	} . . . at 99·5°
8	Sulphur	

It is obvious that when the two substances are united together in this way, they are mixed with oxide of phosphorus, and probably with other impurities. But Mr. Faraday has pointed out a method of procuring the sulphuret of phosphorus in a state of purity. He melted together 5 parts of sulphur and 7 of phosphorus, and agitated the compound in liquid ammonia. On leaving the compound for a few hours in this liquid it lost its reddish brown colour, became light yellow, transparent, and of greater fluidity. Thus purified, it did not become solid at the temperature of 20°, and was very fluid at 32°. On standing some weeks in a bottle of water it deposited pure crystal of sulphur, and a compound remained not so fluid as the former, and which, at the temperature of about 40°, became a crystalline mass. Mr. Faraday endeavoured to analyze this compound; but his experiments were not attended with complete success. However, he succeeded in showing that the proportion of the two constituents approaches 4 sulphur and 8 phosphorus. This would be a disulphuret of phosphorus, or a compound of

1 atom sulphur	.	.	2
2 atoms phosphorus	.	.	4
			—
			6

I analyzed a specimen of the compound which I formed by Mr. Faraday's process, and found it a sesquiphosphuret of sulphur, or a compound of

$1\frac{1}{2}$ atom phosphorus	.	.	3
1 atom sulphur	.	.	2
			—
			5

Probably still other proportions are capable of combining.

XII. According to Brugnatelli, there may be formed a gaseous triple compound of phosphorus, sulphur, and hydrogen, to which the name of *hydrophosphuret of sulphur* may be given. The process is as follows: Put into a small flask or retort a mixture of an ounce and a half of quicklime recently slacked, 40 grains of phosphorus, and 120 grains of sulphuret of potassium dry and pulverized. Pour upon this mixture half an ounce of water, and raise the whole to a boiling temperature. There rise in the first place thick fumes of phosphorus, which burn in consequence of the air contained in the vessel; then the gas is evolved, which Brugnatelli considered as a hydro-phosphuret of sulphur. It must be washed with lime-water to separate some sulphuretted hydrogen gas and phosphoric acid with which it is mixed. The only properties of this gas which he has described, are the following:

It is invisible and possesses the mechanical properties of common air. It does not burn spontaneously; but when mixed with common air or oxygen gas, and kindled, it explodes with great violence. When a flask with a narrow mouth is filled with it, and held to the flame of a candle, it takes fire, and burns with a feeble phosphoric flame, and the flask is filled with white fumes consisting of phosphoric acid, sulphurous acid, and water. Water does not sensibly absorb this gas. When agitated with different metallic solutions it precipitates them. Though these properties are insufficient to demonstrate that this gas is new, and not a mixture of two or more gases already known; yet I have thought it right to notice the gas here in order to draw the attention of chemists to it, and induce some person to subject it to the requisite examination, in order to confirm or refute the opinion of Brugnatelli.

XIII. *Chlorophosphuret of sulphur.* We have also a triple compound of chlorine, phosphorus, and sulphur, discovered by Serullas, and called by him chlorophosphuret of sulphur. To form it we have only to put a quantity of perchloride of phosphorus into a glass vessel filled with dry sulphuretted hydrogen gas, and to shut the mouth of the vessel. In a little time the perchloride is converted into a colourless liquid, while at the same time, a quantity of muriatic acid is formed. This liquid is the chlorophosphuret of sulphur.

It has a specific gravity higher than that of water, a peculiar smell which is pungent and aromatic. In the open air it gives out vapours which have something of the smell of sulphuretted hydrogen. It boils when heated to 257°. It

may be distilled over without any alteration.   When passed
through hot black oxide of copper, no water is formed, nor any
gas given out, showing that it contains no hydrogen.   From
the analysis of Serullas, it appears to be a compound of

$1\frac{1}{2}$ atom chlorine	.	.	6·75
1 atom sulphur	.	.	2
1 atom phosphorus	.	.	2
			10·75

Its atomic weight is 10·75.   During its formation an atom of
chlorine had been separated from the phosphorus, and an atom
of sulphur substituted.   The hydrogen of the sulphuretted
hydrogen decomposed was converted into muriatic acid by
combining with chlorine disengaged.[*]

Oxichloride
of sulphuret-
ted carbon.
XIV. *Oxichloride of sulphuretted carbon.*   There is still
another compound into which this most prolific substance enters
—composed of no fewer than 4 elements; namely, oxygen,
chlorine, carbon, and sulphur, in determinate proportions.   It
was discovered in 1812 by Berzelius and Marcet.   The method
of forming it is this : Put into a vessel incompletely closed 1
part of bisulphuret of carbon, and pour over it 16 parts of a
mixture of nitric and muriatic acids, both concentrated, and set
the whole aside for two or three weeks.   The bisulphuret
acquires in the first place a reddish yellow colour, and gradu-
ally assumes greater consistence, till in about three weeks it is
converted into a white crystalline substance like camphor.
This is the substance in question. •

It has an acrid and disagreeable odour somewhat analogous
to that of chloride of sulphur.   Its taste is first caustic and then
sour.   It does not act on dry litmus paper; when the paper
is moist it instantly reddens it.   Heat readily melts it, and on
cooling it again crystallizes.   It may be distilled over by a
strong heat without undergoing decomposition.   When heated
in close vessels it sublimes like camphor, and crystallizes on
the sides of the vessel.   The crystals are transparent and colour-
less, and appear to be cubes.   It is insoluble in water ; though
it is decomposed when left long in contact with that liquid.

It dissolves in alcohol, ether, fixed and volatile oils, and in
bisulphuret of carbon.   Its solution in alcohol has a very acid
taste, and at the same time very disagreeable.   When mixed
with an alcoholic solution of nitrate of silver, no precipitate
appears at first, but chloride of silver gradually makes its

* Ann. de Chim. et de Phys. xlii. 25.

appearance.   Water throws most of it down from the alcoholic
solution.   Caustic potash dissolves it slowly.   The solution
contains chlorine, carbonic acid, and sulphurous acid.   When
passed through red-hot iron filings or wire, it undergoes decom-,
position, chloride and sulphuret of iron are formed, while
carbonic acid and carbonic oxide gases are disengaged.   By
this method Berzelius analyzed it, and found its constituents
to be

2 atoms chlorine	.	.	9
2 atoms oxygen	.	.	2
1 atom sulphur	.	.	2
1 atom carbon	.	.	0·75

$$13·75$$

So that it contains 6 atoms, and its atomic weight is 13·75.

Perhaps it may be a compound of 1 atom of chlorocarbonic
acid, and 1 atom of a similar but unknown substance, composed
of 1 atom chlorine, one atom oxygen, and one atom sulphur,
and which might be called *chlorosulphurous* acid.

Such are the properties of sulphur, and such the compounds
which it forms with those bodies already described.   Many
more of its compounds will come into view as we proceed.
For there is scarcely any body, except oxygen, capable of
entering into so many combinations as sulphur.

SECTION VIII.—OF SELENIUM.

The copper mine at Fahlun in Sweden contains abundance
of iron pyrites, from which sulphur was extricated by heat to
supply a small sulphuric acid manufactory belonging to Messrs.
Gahn, Eggertz, and Berzelius.   After the combustion of this
sulphur (which was very impure) there remained at the bottom
of the leaden chamber a red or brownish matter, which attracted
the attention of Professor Berzelius.   It was found to consist
chiefly of sulphur.   But when the sulphur was drawn off, there
remained a dark coloured matter, which, when heated before
the blow-pipe, emitted a very strong smell of horseradish.   This
smell led to a more rigid examination of the deposite, in order
to separate the substance to which this smell was owing, and
to investigate its properties.   In this investigation he was
successful.   He separated a combustible substance possessed
of peculiar properties, to which he gave the name of *selenium.*

The selenium in the residue from the manufactory was

* From σελήνη, *the moon;* indicating its relation to tellurium.

mixed with at least eight foreign substances, from which it was separated by a very complicated and tedious process. But the essential part of the whole was digesting the residue in nitro-muriatic acid, by which the selenium was acidified. The mass was now digested in water, and the whole thrown upon a filter. The liquor which passed through contained the selenic acid, still contaminated with several other bodies. But if an excess of sal-ammoniac be added to the liquid, the selenium is thrown down and may be obtained pure by washing it sufficiently in water.*

Preparation.   M. Lewenau found the following process the most economical for obtaining this substance. He put a pound of the reddish brown residue from the combustion of sulphur from pyrites into a tubulated retort, and poured over it, by small quantities at a time, a mixture of 8 pounds of muriatic acid of the specific gravity 1·2, and 4 pounds of nitric acid of the specific gravity 1·5. . To the retort was adapted a large globular receiver, from which proceeded a glass tube, plunging into a flask filled with water. After every addition of acid a violent action took place, and abundance of red vapours passed, which gave a reddish yellow colour to the water in the flask. After the whole acid had been added, it was distilled over into the receiver by a gentle heat. The liquid in the receiver was then poured back and redistilled; then a pound and a half of strong nitric acid was poured upon the matter in the retort, which had a deep red colour, and distilled off. The residue was finally boiled with a sufficient quantity of distilled water, and the whole thrown on the filter.

    Into the liquid which contained the selenium in the state of selenious acid fresh *sulphite of ammonia* was poured. The selenium was precipitated in the state of large red flakes. It was washed with distilled water, and dried; when the liquid was concentrated by evaporation, and sulphite of ammonia added, an additional portion of selenium was precipitated. The acid products of the distillation not being precipitated by sulphite of ammonia, bars of zinc were put into it, which threw down a little more selenium. The quantity obtained from a pound of the red matter by this process amounted to 592·8 grains.†

    When selenium, thus obtained, is exposed to a heat rather

* Berzelius, Annals of Philosophy, xiii. 403.
† Annals of Philosophy (2d series), viii. 104.

higher than that of boiling water, it melts, and on cooling becomes solid. In this state it has the metallic lustre and a deep brown colour. Its fracture is conchoidal, has a vitreous lustre, and the colour of lead. Its powder is a deep red; but it sticks together readily when pounded, and then assumes a grey colour and a smooth surface. In very thin coats it is transparent, with a ruby red colour.

It crystallizes with difficulty in cubes or four-sided prisms, terminated by pyramids. But the crystals are always too minute to enable us to determine the shape with accuracy. Its specific gravity varies from 4·3 to 4·32.

It is easily scratched by a knife. It is brittle like glass, and easily reduced to powder.

When heated, it softens; at 212° it is semi-liquid; and it melts completely at a temperature a few degrees higher. After cooling, it retains for a long time a soft and semifluid state. Like Spanish wax, it may be kneaded between the fingers and drawn out into long threads, which have a great deal of elasticity, and possess transparency when they are flat and thin. These threads, viewed by transmitted light, are red; but by reflected light they are grey, and have the metallic lustre. When selenium is heated in a retort, it begins to boil at a temperature below that of a red heat. It assumes the form of a dark yellow vapour, not so intense as the vapour of sulphur; but more intense than chlorine gas. The vapour condenses in the neck of the retort in black drops, which unite into larger drops, as in the distillation of mercury. When selenium is heated in the air, or in vessels so large that the vapour may be condensed by the cold air, a red smoke is formed which has no particular smell, and which is condensed into a cinnabar red colour, yielding a species of flowers, as happens to sulphur in the same circumstance.

Selenium is a very bad conductor of heat. It is likewise a non-conductor of electricity; yet Berzelius could not succeed in his attempt to render it electric by friction.

II. Selenium combines with three portions of oxygen, and forms three compounds, which have received the names of *oxide of selenium*, *selenious acid*, and *selenic acid*. **Combinations with oxygen.**

1. Berzelius did not succeed in obtaining the oxide of selenium in a separate state. He considers it as a gaseous body. It is formed whenever selenium is strongly heated in the open air, and is distinguished by an exceedingly strong **Oxide.**

smell of horseradish. It is not absorbed by water, nor is it capable of uniting with acids.

2. Selenious acid may be formed by burning selenium in oxygen gas, or by heating it in contact with nitric acid or nitromuriatic acid. When the solution cools, the selenious acid is deposited in large prismatic crystals, longitudinally striated, and similar to those of nitrate of potash. Selenious acid sublimes at a lower heat than is necessary to distil over sulphuric acid. It condenses in the form of long four-sided needles. Its vapour resembles in colour chlorine gas. Its taste is acid, and it leaves a slightly burning sensation upon the tongue. It is very soluble in water and in alcohol.

It follows from a set of experiments by Berzelius, of which an account will be given below, that selenious acid is a compound of

Selenium . . 100
Oxygen . . 40·43

Now, if it consists of 2 atoms of oxygen united to 1 atom of selenium (as is probable), we have an atom of oxygen to an atom of selenium, as 1 : 4·94. Hence an atom of selenium should weigh 4·94, and an atom of selenious acid 6·94. These numbers are corroborated by the analyses of two selenites given by Berzelius. These are as follows:

Selenite of barytes.		Selenite of soda.	
Selenious acid 100·0 . . 6·899		Selenious acid 64·5 . . 7·267	
Barytes —— 137·7 . . 9·5		Soda —— 35·5 . . 4·000	

The first of these analyses gives us 6·899, and the second 7·267 for the atomic weight of selenious acid. The mean of the two gives us 7·083. We cannot therefore be far from the truth if we pitch upon 7 as the true atomic weight of this acid.

3. Selenic acid was discovered by Mitcherlich in 1827.[*] The name selenic acid had been previously given to the preceding acid, the only one noticed by Berzelius. Selenic acid may be obtained by detonating an intimate mixture of 1 part of selenium and three parts of nitre in small quantities at a time, in a red-hot crucible. The residue, which contains seleniate of potash, is to be dissolved in water and nitrate of lead added to the neutralized solution till all the selenic acid is thrown down in the state of seleniate of lead. This powder is

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[*] Ann. de Chim. et de Phys. xxxvi. 100.

carefully washed, diffused in water, and a current of sulphuretted hydrogen gas passed through it till the whole lead is converted into sulphuret. The liquid being now filtered and heated to drive off the sulphuretted hydrogen which it contains, is an aqueous solution of selenic acid.

It may be concentrated by evaporation till its temperature reaches 536°. But if we raise the heat higher oxygen gas is given out and the acid changed to the selenious. Its specific gravity is 2·60. It resembles sulphuric acid in its consistence and in the heat evolved when it is mixed with water. It contains about 16 per cent. of water, which is rather less than an atom and a half of water united to an atom of acid. We cannot reduce the water to 1 atom without decomposing a portion of the acid. This acid was analyzed by M. Mitcherlich, and found by him to be a compound of

1 atom selenium	. .	5
3 atoms oxygen	. .	3
		8

Thus it appears that selenious and selenic acids resemble sulphurous and sulphuric acid in their constitution. There is also a good deal of analogy in their characters. We do not know the composition of oxide of selenium; but analogy would lead to the conclusion that it is a compound of one atom selenium and one atom oxygen. On that supposition the constitution of the three compounds of selenium and oxygen will be as follows :

	Selenium.	Oxygen.	Atomic weight.
Oxide of selenium	1 atom	+ 1 atom .	6
Selenious acid	1	+ 2 .	7
Selenic acid	1	+ 3 .	8

III. Chlorine and selenium appear to combine in two dif-

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* Mitcherlich's experiments give the composition of seleniate of potash,

Selenic acid	.	. .	8·56
Potash	.	.	6
			14·56

and he found that the constituents of selenic acid were

Selenium	.	.	61.4
Oxygen	.	.	38·6
			100

But Berzelius makes the constituents,

Seleninm	.	.	100 or 4·94
Oxygen	.	.	60·66 or 3

ferent proportions and to form a chloride and a bichloride ; the former of which is liquid and the latter solid.

When selenium is put into a glass tube, and a current of chlorine gas passed over it, the selenium absorbs the chlorine and fuses into a brown liquid.   By degrees this liquid, from a farther absorption of chlorine, is converted into a solid matter having a white colour.   When this matter is heated it sublimes without melting, and condenses into small crystals in the upper part of the vessel.   From an imperfect analysis of this matter by Berzelius, there is reason for considering it as a bichloride of selenium or compound of

2 atoms chlorine	. .	9
1 atom selenium	. .	5
		——
		14

When selenium is added to this bichloride it combines with it when assisted by heat, and a deep yellow translucid liquid is obtained which may be distilled over, though it is much less volatile than the bichloride.   It falls to the bottom of water, and continues for some time liquid, but at last is decomposed into muriatic and selenious acids which dissolve in water, and selenium which remains undissolved.   This liquid, according to Berzelius, is a compound of

1 volume chlorine gas,   ⎱ united together and condensed
1 volume selenium vapour, ⎰ into a liquid. If this statement be correct, it is obviously a compound of

1 atom chlorine	. .	4·5
1 atom selenium	. .	5
		9·5

and its atomic weight must be 9·5.

Bromide.   IV. Bromide of selenium was formed by Serullas by pouring bromine upon selenium in powder contained in a glass tube. The two bodies combine rapidly with a noise similar to that of a red-hot iron when plunged into water.   Much heat is evolved, and the whole becomes solid.   The bromide formed has a reddish brown colour, gives out vapours, and has the smell of chloride of sulphur.   Water dissolves it, converting it into selenious acid and hydrobromic acid.*   From this decomposition the bromide ought to be a compound of

* Ann. de Chim. et de Phys. xxxv. 349.

2 atoms bromine . . 20

1 atom selenium . . 5

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25

V. No experiments have been made to determine the nature of the combinations of selenium with iodine and fluorine.

VI. Selenium combines with hydrogen, and forms a gaseous substance, which has been distinguished by the name of *selenietted hydrogen gas.*

Selenietted hydrogen.

When selenium and potassium are fused together, a compound is formed, which dissolves in water without the evolution of any elastic fluid. The liquid has the colour of beer, and contains hydroseleniet of potash. When muriatic acid is added, a considerable proportion of the selenium is precipitated, and the liquid acquires the smell of sulphuretted hydrogen, but no effervescence takes place, unless the solution be very concentrated. When diluted muriatic acid is poured upon the seleniet of potassium in a small retort, the seleniet becomes red, an effervescence takes place, and selenietted hydrogen gas is driven off.

This gas is colourless, and possesses the mechanical properties of common air. Its smell is at first similar to that of sulphuretted hydrogen; but it speedily acts with great energy upon the organs of smell and the throat, occasions a painful feeling, destroying the sense of smell, and producing a severe cough, with a copious expectoration. These feelings are not speedily removed; and Berzelius is of opinion that a free inhalation of this gas into the nostrils would probably be attended with dangerous consequences.

This gas is more soluble in water than sulphuretted hydrogen. The aqueous solution of it precipitates all the metals from their solutions, and the colours of the precipitates are black or brown, except those from manganese, zinc, and serium, which are flesh coloured. This gas reddens vegetable blues, and possesses other acid characters. It is decomposed by the united action of air and water.

In order to determine the composition of this gas, Berzelius caused a current of it to pass through acetate of silver. The seleniet of silver formed weighed 1·888. It was dissolved in nitric acid, and thrown while boiling hot into dilute muriatic acid. The chloride of silver formed weighed 1·844, which is equivalent to 1·389 silver. Hence we see that seleniet of silver is composed of

Silver	.	.	1·389
Selenium	.	.	0·499

1·888

But the silver in the acetate was in the state of an oxide, and was combined with 0·101 oxygen. This oxygen had been separated by the hydrogen of the selenietted hydrogen gas, which had converted the oxygen of the oxide into water, while the selenium united with the reduced silver. But oxygen, in order to form water, must be combined with $\frac{1}{8}$th of its weight of hydrogen. Hence the hydrogen united with the 0·499 selenium in the gas was 0·012625. Thus we have selenietted hydrogen gas composed of

Selenium	.	.	499	or 5·
Hydrogen	.	.	12·625	0·126*

It is obvious from this that selenietted hydrogen gas is a compound of 1 atom selenium and 1 atom hydrogen, or of

Selenium	.	.	5·
Hydrogen	.	.	0·125

Analogy leads us to conclude that this gas, like sulphuretted hydrogen, is a compound of one volume hydrogen gas, and one volume selenium vapour, condensed into 1 volume. Hence the knowledge of its specific gravity would enable us to determine the specific gravity of the vapour of selenium.

This gas possesses acid properties like sulphuretted hydrogen, and like it, combines with various bases, and forms salts.

VII. Nothing is known respecting the combinations of selenium with azote, carbon, boron, and silicon.

Phosphuret.　VIII. When selenium is dropped into melted phosphorus, it dissolves rapidly, and the compound sinks through the liquid phosphorus in red streaks. These streaks speedily dissolve; and selenium may be mixed with melted phosphorus in any proportion. When phosphorus is saturated with selenium we obtain a very fusible compound, which has a dark brown colour, a good deal of lustre, and a vitreous fracture. If the mixture contains an excess of phosphorus, a superphosphuret of selenium may be distilled off in red drops, which are semi-transparent and destitute of the metallic lustre. When this phosphuret is digested in water, selenietted hydrogen gas is formed, and some selenium precipitates. It dis-

* Ann. de Chim. et de Phys. ix. 335.

solves in caustic potash, and the liquid is found to contain phosphate and hydroseleniate of potash, and selenium is gradually precipitated.*

IX. When sulphuretted hydrogen gas is passed through a solution of selenic acid in water, a sulphuret of selenium is formed, which renders the liquid muddy and lemon yellow, but does not easily precipitate. The precipitation is facilitated by the addition of some muriatic acid to the liquid. The sulphuret thus obtained has a deep orange colour; it softens at 212°, and becomes liquid at a temperature a few degrees higher. At a still higher temperature it boils, and may be distilled over. The portion distilled over is transparent, has a reddish orange colour, and resembles melted orpiment. This sulphuret is not easily acidified by nitric acid. Nitromuriatic acid acts much more powerfully. It dissolves in the caustic fixed alkalies, and in the hydrosulphurets; the solution has a very dark orange colour. The acids precipitate from it a sulphuret of selenium.

This sulphuret of selenium, according to the analysis of Berzelius, is composed of 100 parts selenium, united to $60\frac{3}{4}$ of sulphur.† This approaches very nearly to 3 atoms of sulphur and 2 atoms of selenium. For

3 atoms sulphur	.	.	= 6	. .	60
2 atoms selenium	.	.	= 10	. .	100

Hence it seems to be a sesquisulphuret of selenium.

Selenium is unfortunately still a very scarce substance. It would appear from observations made in Germany and Great Britain, that it exists pretty frequently in minute quantities in iron pyrites. Mr. Zinker has lately discovered it in the Hartz combined with lead in considerable quantity. The seleniet of lead has so close a resemblance to sulphuret of lead, that the one may be easily mistaken for the other. Probably, therefore it may be hereafter discovered in lead mines along with galena.

The analogy between selenium and sulphur is very remarkable. We may expect, therefore, hereafter, to discover a similar set of compounds formed by selenium, to those which we at present know, formed by means of sulphur.

SECTION IX.—OF TELLURIUM.

I. The mine of Mariahilf, in the mountains of Fatzbay, near

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* Berzelius, Ann. de Chim. et de Phys. ix. 238.   † Ibid. 236.

Zalethna, in Transylvania, contains an ore of a bluish white colour and a metallic lustre; concerning the nature of which mineralogists were for a long time doubtful. That it contained a little gold was certain; but by far the greatest part of it consists of a metallic substance, which some supposed to be bismuth, others antimony. Muller of Reichenstein examined it in 1782;[*] and concluded, from his experiments, that this ore, which had been distinguished by the names of *aurum problematicum,* *aurum parodoxicum,* and *aurum album,* contains a new metal different from every other. Being still dissatisfied with his own conclusions, he sent a specimen of it to Bergman; but the specimen was too small to enable that chemist to decide the point. He ascertained, however, that the metal in question is not antimony. The experiments of Muller appeared so satisfactory, that they induced Mr. Kirwan, in the second edition of his Mineralogy, published in 1796, to give this metal a separate place, under the name of *sylvanite.* Klaproth published an analysis of the ore in 1798, and completely confirmed the conclusions of Muller.[†] To the new metal, which constitutes 0·925 of the ore, he gave the name of *tellurium;* and this name has been generally adopted. Gmelin examined the ore in 1799;[‡] and his experiments coincide almost exactly with those of Muller and Klaproth. By these philosophers the following properties of tellurium have been ascertained. Some curious new combinations of tellurium were discovered by Davy in 1809;[§] and a set of important experiments were made upon it by Berzelius in 1812.[||]

1. Tellurium has a silver white colour, and considerable brilliancy; its texture is laminated like antimony. It is a worse conductor of electricity than antimony and bismuth, but better than pyrites.

2. Its hardness has not been ascertained. Its specific gravity, according to Klaproth, is 6·115.[¶] Magnus found it 6·1379.

3. It is very brittle, and may be easily reduced to powder.

4. It melts when raised to a temperature somewhat higher than the fusing point of lead. If the heat be increased a little, it boils and evaporates, and attaches itself in brilliant drops to the upper part of the retort in which the experiment is made.

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[*] Born, ii. 468.   [†] Crell's Annals, 1798, i. 91.
[‡] Ibid. 1799, i. 275 and 365.   [§] Phil. Trans. 1810, p. 16.
[||] Nicholson's Journal, xxxvi. 129. Unfortunately this paper of Berzelius is so inaccurately printed, that in many places it is quite unintelligible.
[¶] Muller found it 6·343; but probably his specimen was not pure.

It is, therefore, next to mercury and arsenic, the most volatile of all the metals. When cooled slowly it crystallizes.

II. Tellurium combines with only one proportion of oxygen, and forms a compound possessing acid properties. It might be called *telluric acid.* But as it likewise possesses alkaline properties, it will be better to retain the common name, *oxide of tellurium.*

1. When tellurium is exposed to the action of the blowpipe Oxide. upon charcoal, it takes fire, and burns with a lively blue flame, the edges of which are green; and is completely volatilized in the form of a white smoke, which, according to Klaproth, has a smell not unlike that of radishes.*

This white smoke is the oxide of tellurium, which may be obtained also by dissolving the metal in nitro-muriatic acid, and diluting the solution with a great quantity of water. A white powder falls to the bottom, which is the oxide. It may be procured also by dissolving the metal in nitric acid, and adding potash slowly till the oxide precipitates. This oxide is easily melted by heat into a straw-coloured mass of a radiated texture. When made into a paste with oil, and heated in charcoal, it is reduced to the metallic state so rapidly, that a kind of explosion is produced. It may be volatilized by the application of heat. When heated on a bit of charcoal before a bellows it becomes first yellow, then orange, and lastly of a fine red.† After fusion it produces no change on litmus paper. But it combines with the different bases, and forms with them neutral salts. It dissolves also in acids, and forms neutral salts with them likewise.

According to the experiments of Klaproth,‡ this oxide is Atomic weight. composed of

Metal	. .	100
Oxygen	. .	20

But Berzelius found the weight of oxygen somewhat greater. According to his experiments,§ the oxide is composed of

Metal	. .	100
Oxygen	. .	24·8

If we suppose the real quantity of oxygen that unites with 100 metal to be 25, or $\frac{1}{4}$th of the weight of the metal, and

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* Gmelin could not perceive this smell, nor was it perceived by Berzelius.
† Berzelius; Nicholson's Journal, xxxvi. 130.   ‡ Beitrage, iii. 14.
§ Annals of Philosophy, iii. 250.

that this oxide is a compound of 1 atom metal $+$ 1 atom oxygen, then the weight of an atom of tellurium will be 4.

III. Tellurium burns spontaneously when introduced into chlorine gas. The *chloride of tellurium* formed is white, and semitransparent. When heated it rises in vapour, and crystallizes. Water decomposes it, and separates a white powder consisting of oxide of tellurium united to water, or *hydrated oxide*, as such compounds are called. According to Davy it is composed of

Tellurium   .   .   2
Chlorine   .   .   1·83

These numbers approach nearest to one atom tellurium and one atom chlorine. But they do not entirely agree with that supposition.*

Iodide.

IV. Iodine combines very readily with tellurium when the two substances are brought into contact. The solution in water has a dark purple red colour. It combines readily with potash, and forms a colourless solution, which yields by evaporation small white prisms.†

V. Nothing is known respecting the combination of tellurium with fluorine or azote.

Telluretted hydrogen.

VI. Tellurium has the property of combining with hydrogen, and of forming a gaseous substance, to which the name of *telluretted hydrogen gas* has been given.

It was discovered by Sir Humphry Davy in 1809,‡ and some experiments on it by Berzelius, were published in 1813.§

It is formed by mixing together oxide of tellurium, potash, and charcoal; and exposing the mixture to the action of a red heat. It is then put into a retort; diluted sulphuric acid is poured on it, and the beak of the retort is plunged into a mercurial trough. A gas comes over, which may be collected in glass jars previously filled with mercury. This gas has been but imperfectly examined, owing to the difficulty of procuring tellurium in sufficient quantity for experimental purposes. The following are its properties, as far as they have been ascertained.

It is transparent and colourless, and possesses the mechanical properties of common air. It has a strong peculiar smell,

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* Davy; Elements of Chemical Philosophy, p. 409.
† Ruhland; Schweigger's Journal, xi. 140.
‡ Phil. Trans. 1810, p. 16; or Nicholson's Journal, xxvi. 333.
§ Nicholson's Journal, xxxvi. 132.

bearing considerable resemblance to that of sulphuretted hydrogen. It burns with a bluish flame, and oxide of tellurium is deposited. It is soluble in water, and gives that liquid a claret colour. Davy was not able to determine whether it reddens vegetable blues. But in other respects it possesses the properties of an acid, combining with alkalies, and precipitating most metallic solutions like sulphuretted hydrogen. There is reason to suspect that this compound may be formed by heating tellurium in hydrogen gas. Chlorine gas immediately decomposes it. The compound of telluretted hydrogen and potash is immediately decomposed when the solution of it is exposed to the air. Berzelius has endeavoured to show by indirect experiments that the gas is a compound of

Tellurium	. .	100	. .	4
Hydrogen	. .	3·1	. .	0·125

Supposing these proportions correct, it is obviously a compound of 1 atom tellurium + 1 atom hydrogen.

Ritter, in 1808, discovered that when tellurium is connected with the negative pole of a galvanic battery, and the circuit completed by dipping the tellurium in water, a brown powder is formed, which appears to be a solid compound of tellurium and hydrogen.

VII. It would appear from an experiment of Berzelius, that tellurium is capable of combining with carbon.* The compound is a black powder; but its properties have not been examined.

VIII. No experiments have been made on the combination of tellurium with boron, silicon, or phosphorus. It may be combined with sulphur by fusion. The *sulphuret* has a leaden grey colour, and a radiated texture. On red hot coals it burns with a green flame.†

IX. Berzelius combined tellurium with selenium; the two substances unite readily, and with the production of heat. This compound is very fusible; when heated it boils and sublimes in dark brown drops. It is easily oxydized and converted into seleniate of tellurium. The texture of this seleniet is very crystalline. Its colour is that of iron, but rather darker.‡

SECTION X.—OF ARSENIC.

I. The word *arsenic* (ἀρσενικον) occurs first in the works of Dios- History.

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* Nicholson's Journal, xxxiv. 133.   † Klaproth's Beitrage, iii. 12.
‡ Berzelius, Ann. de Chim. et de Phys. ix. 249.

corides, and some other authors who wrote about the beginning of the Christian era. It denotes in their works the same substance which Aristotle had called σανδαραχη,* and his disciple Theophrastus ἀῤῥενικον, which is a reddish coloured mineral, composed of arsenic and sulphur, used by the ancients in painting, and as a medicine.

The *white oxide of arsenic*, or what is known in commerce by the name of arsenic, is mentioned by Avicenna in the 11th century; but at what period the metal called arsenic was first extracted from that oxide is unknown. Paracelsus seems to have known it; and a process for obtaining it is described by Schroeder in his Pharmacopœia, published in 1649.† But it was only in the year 1733 that this metal was examined with chemical precision. This examination, which was performed by Mr. Brandt,‡ demonstrated its peculiar nature; and since that time it has been always considered as a distinct metal, to which the term *arsenic* has been appropriated. Its properties were still farther investigated by Macquer in 1746,§ by Monnet in 1773,|| by Bergman in 1777.¶ To the labours of these philosophers, and to those of Mr. Scheele,** we are indebted for almost every thing known about the properties of this metal. Its combinations with oxygen have been carefully examined by Proust,†† Bucholz,‡‡ Berzelius,§§ and some other chemists.|| ||

Properties.

1. Arsenic has a bluish white colour not unlike that of steel, and a good deal of brilliancy. It has no sensible smell while cold: but when heated it emits a strong odour of garlic, which is very characteristic.

2. It is the softest of all the metallic bodies, and is so brittle that it may be easily reduced to a fine powder by trituration

* Pliny seems to make a distinction between sandaracha and arsenic. See lib. xxxiv. cap. 18.

† Bergman, ii. 278.

‡ His paper was published in the Memoirs of the Philosophical Society of Upsala, for 1733, p. 39. He describes the properties of arsenious acid with precision, and gives the first accurate process for procuring arsenic in the metallic state. He mixed white arsenic with potash and volatile alkali, and fused the mixture in a well luted crucible. Bergman seems to have taken many of his facts respecting arsenic from Brandt's paper.

§ Mem. Par. 1746, p. 223, and 1748, p. 35. || Sur l'Arsenic.

¶ Opusc. ii. 272. ** Scheele, i. 129.

†† Jour. de Phys. ‡‡ Jour. de Chim. iv. 5.

§§ Ann. de Chim. lxxx. 9, and Annals of Philosophy, iii. 93.

|| || See Annals of Philosophy, iv. 171.

in a mortar. Its specific gravity, when melted, is 5·7633.* According to the trial of Mr. Harepath, the specific gravity of pure metallic arsenic is 5·672.† Berzelius states its specific gravity at 5·7. Guivour found that if it was exposed to a red heat in a porcelain retort filled with it, and allowed to cool, it acquires much greater brilliancy, and its specific gravity becomes 5·959.‡

3. Its fusing point is not known, because it is the most volatile of the metals, subliming without melting, when exposed in close vessels, to a heat of 365°.§ When sublimed slowly, it crystallizes in tetrahedrons.

II. It may be kept under water without alteration; but when exposed to the open air, it soon loses its lustre, and often becomes black, and falls into powder, though this is not always the case.

Compound with oxygen.

Arsenic is capable of combining with two doses of oxygen, and of forming two compounds, which possess acid properties, and which have been denominated *arsenious* and *arsenic acids.*

Arsenious acid.

1. When exposed to a moderate heat in contact with air, it sublimes in the form of a white powder, and at the same time emits a smell resembling garlic. If the heat be increased, it burns with a pale blue flame. Arsenic indeed is one of the most combustible of the metals. The substance which sublimes was formerly called *arsenic* or *white arsenic,* and is still known by these names in the commercial world. It is now denominated *arsenious acid.* It is seldom prepared by chemists, because it exists native, and is procured abundantly during the extraction of the other metals from their ores.

When obtained by these processes, it is a white, brittle, compact substance, of a glassy appearance. It has a weak but acrid taste, which at last leaves an impression of sweetness, and is one of the most virulent poisons known.

According to the experiments of Klaproth, 1000 parts of cold water dissolve only $2\frac{1}{2}$ parts of this acid, while 1000 parts of boiling water dissolve $77\frac{3}{4}$ parts of it.‖ This solution has a weak taste, and reddens vegetable blues. When it is slowly evaporated, the oxide crystallizes in regular octahedrons. It

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* Lavoisier's Elements, p. 572. I found its specific gravity when sublimed 5·235. Bergman states the specific gravity of arsenic to be 8.31, (Opusc. ii. 279,) and Brandt makes it 8·308. But the specimens which they tried must have been impure.

† Phil. Mag. lxiv. 322.   ‡ Jour. de Chim. Med. ii. 55.
§ Bergman, ii. 279.   ‖ Annals of Philosophy, iv. 132.

Chap. II.

is soluble also in between 70 and 80 times its weight of alcohol, and in oils. This acid sublimes when heated to 383°; if heat be applied in close vessels, it becomes pellucid like glass; but when exposed to the air, it soon recovers its former appearance. The specific gravity of this glass is 3·639;[*] that of the acid in its usual state is 3·706,[†] and according to Mr. Harepath 3·729.[‡]

Many experiments have been made to determine the quantity of oxygen in this acid. According to Berzelius, whose experiments were made with the greatest care, it is a compound of

<div style="text-align:center">

Arsenic   .   .   100
Oxygen   .   .   31·907[§]

</div>

I found that 6·75 parts of arsenious acid when converted into arsenic acid, became 7·75 parts. It is obvious from this that arsenic acid contains just 1 atom more of oxygen than arsenious acid.

When arsenious acid is mixed with black flux, and slowly heated to redness in a matrass or retort, the arsenic is reduced to the metallic state, and slowly sublimes. By this means the metal may be procured in a state of purity. This method of reducing arsenic was first pointed out by Brandt, to whom we are indebted for the knowledge of most of the properties of arsenious acid above described.

Arsenic acid.

2. Arsenic is capable of combining with an additional dose of oxygen, and of forming another compound, first discovered by Scheele, known by the name of *arsenic acid*. The process prescribed by Scheele is to dissolve three parts of arsenious acid in seven parts of muriatic acid, to add five parts of nitric acid, to put the mixture into a retort, and distil to dryness. The dry mass is to be merely brought to a red heat, and then cooled again. It is solid arsenic acid. Mr. Bucholz has shown, that the whole quantity of muriatic acid prescribed by Scheele is not necessary. The formula which he considers as the best is the following : Mix together in a crucible 2 parts of muriatic acid of the specific gravity 1·200, 8 parts of arsenious acid, and 24 parts of nitric acid, of the specific gravity 1·25. Evaporate to dryness, and expose the dry mass to a slight red heat.[||] But the easiest method of procuring this acid is to dissolve arsenic in nitric acid, and evaporate the solution to dryness.

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* According to the experiments of Dr. Wollaston.
† Bergman, ii. 286.   ‡ Phil. Mag. lxiv. 322.
§ Afhandlingar, v. 379. || Van Mon's Journal de Chimie. iv. 16.

The acid thus prepared has no very strong taste when dry; but when dissolved in water, it acquires an excessively sour taste, and remains liquid even when evaporated to the consistence of a jelly. It is as noxious as arsenious acid.

This acid, like phosphoric, after being exposed to a red heat does not dissolve completely in water; but leaves a white powder, which, however, is at last dissolved by the long continued action of the water. When exposed to the air it attracts moisture till its specific gravity is reduced to 1·935. By evaporation we obtain a syrupy liquid of the specific gravity 2·55 (as determined by Vogel). When concentrated till the temperature rises to 248° it begins to deposite a solid matter. When the anhydrous acid is exposed to the air it slowly imbibes moisture, and at a certain period forms large crystals (according to Mitcherlich), which are more deliquescent than chloride of calcium.

Arsenic acid acts with considerable energy as an acid, combining with the bases, and forming salts, to which the name of *arseniates* has been given. Mitcherlich has shown that crystals of the arseniates and phosphates have the same shape.

This acid according, to the experiments of Berzelius, is composed of

$$\begin{array}{lll} \text{Arsenic} & \ldots & ,100 \\ \text{Oxygen} & \ldots & 53\cdot187 \end{array}$$

Thus it appears from Berzelius's experiments that the oxygen in arsenious acid united to a given weight of arsenic, is to that in arsenic acid as 31·907 to 53·187, or as 2 to 3⅓, or as 3 to 5.

I found that 4·75 parts of arsenic, when converted into arsenic acid by solution in nitric acid, weighed 7·75, and that 6·75 parts of arsenious acid when converted into arsenic acid became 7·75. From these two experiments I concluded that the composition of these two acids was as follows:

		Arsenic.		Oxygen.		
Arsenious acid	. .	4·75	+	2	=	6·75
Arsenic acid	. .	4·75	+	3	=	7·75

But it is evident from the experiments of Dumas on arsenietted hydrogen gas, to be mentioned hereafter, that arsenious acid is a compound of 1 atom arsenic and 1½ atom oxygen, and this is confirmed by the analogy between the chloride, iodide, bromide, sulphuret, and compound of arsenic and hydrogen. It is clear then that my experiments must have been inaccurate. Berzelius's determination of the constitution of arsenic acid is also put beyond doubt by the experiments of Dumas. Indeed

the perfect analogy between phosphoric and arsenic acid can leave no doubt that their constitution is the same. The constituents of the arsenious and arsenic acids then are undoubtedly as follows:

	Arsenic.		Oxygen.		Atomic weight.
Arsenious acid . .	4·75	+	1·5	. .	6·25
Arsenic acid . . .	4·75	+	2·5	. .	7·25

Composition.

As arsenious acid is one of the most virulent poisons, and as its taste is comparatively mild, it is much more frequently employed to destroy life than any other substance. In cases of death, where poison is suspected, it is frequently requisite to examine the contents of the stomach after death in order to ascertain whether it contain arsenic, and thus produce incontestible proof of the administration of poison.

Method of detecting arsenious acid.

The first step in such cases is to filter the matter contained in the stomach, diluted if necessary with a portion of boiling-hot distilled water. If the filtered liquid thus obtained be colourless or nearly so, a few drops of water impregnated with sulphuretted hydrogen gas is to be added to it. If arsenic be present it will assume a yellow colour, and on adding a drop or two of acetic acid a yellow precipitate will fall. If no arsenic be present the yellow colour will not appear. When the liquid contained in the stomach happens to be dark coloured the yellow colour may not appear; yet if arsenic be present, even in very minute quantity, a precipitate will fall within a few hours. This precipitate like the former is a sulphuret of arsenic, and may be employed like it in the subsequent steps requisite for fully establishing the presence of arsenic.

Collect this precipitate on a filter of smooth paper, dry it, and mix it with a little black flux,* and put the mixture into the bottom of a thin glass tube shut at one end. The tube may be 5 or 6 inches long and about $\frac{1}{4}$ inch in diameter. Take care that the whole mixture is collected at the bottom of the tube, and that the inner surface be quite smooth and clean. Apply the bottom of the tube to the flame of a spirit lamp, and continue the heat for a few minutes, taking care not to fuse the glass. The arsenic will be reduced to the metallic state, and subliming will line the inside of the tube about a half inch above the mixture, and by directing the flame upon it, may be sublimed as high as is thought proper. It forms a brilliant

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* Black flux is formed by heating cream of tartar in a crucible till it ceases to give out smoke. It is an intimate mixture of charcoal and carbonate of potash.

coating on the inside of the tube, having the colour and appearance of polished steel. To leave no ambiguity whatever, the tube may be cut off just below the crust of metallic arsenic, and that portion containing the arsenic may be heated in nitric acid. The arsenic will dissolve, and the solution being evaporated to dryness, will leave arsenic acid, which being diluted with water and mixed with a drop of nitrate of silver, will give a brick red precipitate.

Such is the method that I have been accustomed to follow in such cases. It succeeds in detecting the presence of as small a quantity as $\frac{1}{10}$th of a grain. Indeed I have no doubt that with due precautions a much smaller quantity might be detected. With $\frac{1}{100}$th of a grain of white arsenic, the reduced arsenic might be rendered visible by reducing the diameter of the tube sufficiently, and the precipitate of arseniate of silver, by taking the precaution to saturate the arsenic acid in the first place with an alkali, might be made quite distinct.

Many other tests of arsenic have been proposed by chemists. But the preceding method will, I believe, always answer. It seems, therefore, unnecessary to mention others here.*

3. There are some reasons for believing that arsenic is capable of combining with a smaller quantity of oxygen than exists in arsenious and arsenic acids. When obtained by sublimation from a mixture of black flux and arsenious acid, and collected in thin crusts in small Hessian crucibles, it sometimes, when exposed to the air, soon falls in the state of a black powder. Berzelius found that 100 parts of arsenic when thus converted into a black powder, had increased in weight eight parts. This black powder is insoluble both in water and acids. When digested in muriatic acid it recovers the metallic lustre, and the acid is found to have taken up a little arsenious acid. It may therefore perhaps be only an incipient conversion into arsenious acid. If the additional weight were oxygen, the black powder would be a trisoxide composed of

Oxide of arsenic.

> 3 atoms arsenic . . 14·25
> •1 atom oxygen . . 1
>
> 15·25

Like most compounds consisting of two or more atoms of metal.

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* The medical reader who is anxious for farther information may consult Dr. Christison *on poisons*, or Mr. Philip's paper in the Annals of Philosophy (2d series), vii. 30; Mr. Donovon's remarks in the Dublin Journal, ii. 400; and Berzelius's method, Ann. de Chim. et de Phys. xxxix. 109.

with one atom of oxygen, it is possessed neither of the characters of an acid nor a base.

Chloride of arsenic.

III. Arsenic combines with chlorine and forms a compound, which has been called *chloride of arsenic.*

It has been long known and described in chemical books, under the name of *butter of arsenic.* It may be obtained by introducing arsenic into a sufficient quantity of chlorine gas. It burns spontaneously with considerable brilliancy, and forms the chloride. But the easiest method of procuring this chloride in considerable quantity, and pure, is the old one. It is as follows: Mix together 6 parts of corrosive sublimate and 1 part of arsenic, and distil with a gentle heat in a retort, a liquid passes over into the receiver which is the chloride of arsenic.

Another very easy process has been given by M. Dumas. Put into a tubulated retort a quantity of arsenious acid, with about 10 times its weight of sulphuric acid. Raise the temperature to about 212°; then throw into it by the tubulure fragments of common salt that have been recently fused, to expel all moisture. Chloride of arsenic passes slowly into the receiver. The heat must be kept up, and additional portions of common salt added by degrees. Little or no muriatic acid is disengaged; but towards the end of the process, hydrated chloride of arsenic passes over into the receiver, and swims upon the surface of the anhydrous chloride; doubtless in consequence of the sulphuric acid become weaker as the quantity of common salt increases.*

This chloride is transparent and of the consistence of oil. It is very volatile. It boils at 270°. Its specific gravity is greater than that of water. When heated it readily dissolves phosphorus and sulphur; but allows these bodies to precipitate on cooling. It likewise dissolves rosin, and combines with olive oil and oil of turpentine.† When mixed with water it is decomposed, and arsenious acid precipitates. According to the experiments of Dr. John Davy, 2 grains of arsenic, when converted into chloride, absorb 4 cubic inches of chlorine gas.‡ Now

Composition. 4 cubic inches of chlorine gas weigh 3·141 grains. Hence the chloride is a compound of

              Arsenic 2   .   .   or 4·75
              Chlorine 3·114   .   .   or 7·395

7·395 a little exceeds 1½ atoms of chlorine. There seems no doubt from this, that the chloride is a compound of

* Ann. de Chim. et de Phys. xxxiii. 360.
† Dr. John Davy, Phil. Trans. 1812, p. 186.   ‡ Ibid. p. 188.

1½ atom chlorine	.	.	6·75
1 atom arsenic	.	.	4·75

11·50

It is therefore a sesquichloride of arsenic.

Dumas found the specific gravity of the vapour of this chloride to be 6·3006.* Now if we consider this sesquichloride in the state of vapour to be a compound of

1½ volume chlorine, } condensed into one volume, we
1 volume arsenic vapour, } shall have the specific gravity of arsenic vapour by subtracting 1½ volume of chlorine = 3·75 from 6·3006, the specific gravity of the sesquichloride in vapour. The remainder 2·5506 ought to be the specific gravity of arsenic vapour. From the specific gravity of arsenietted hydrogen to be noticed immediately, the specific gravity of arsenic vapour is found to be 2·591.

It is a law that holds with the greater number of gases and vapours, that if we multiply the atomic weight by 0·5555, the product will be the specific gravity of the vapour or gas. Now 4·75 (atom of arsenic) × 0·5555 = 2·6988; a number somewhat higher than that resulting from the specific gravities as determined by Dumas; but the atomic weight of arsenic pitched upon by Dumas, namely, 4·7, would give us 2·5111 for the specific gravity of arsenic vapour; which is nearly as much below the specific gravity found as mine is above it. Berzelius's number is 4·70385, which gives also a specific gravity too low.

Perhaps, in the present state of our knowledge, it will be safest to deduce the specific gravity of the vapour of sesquichloride of arsenic from the atomic weight of arsenic 4·75. It will be 6·4888. This number is about 3 per cent. higher than the specific gravity actually found by Dumas—a difference which a very small admixture of common air would account for.

From an observation of Dumas, it is not improbable that there is another chloride of arsenic containing more chlorine than the sesquichloride. When sesquichloride of arsenic is formed by passing a current of dry chlorine gas over arsenic in powder in those parts of the apparatus where the arsenic is in contact with an excess of chlorine, a white solid matter is formed, which is probably similar in its composition to the perchloride of phosphorus.† But the nature of this substance has not yet been investigated.

* Ann. de Chim. et de Phys. xxxiii. 361.   † Ibid. 359.

IV. The bromide of arsenic was first described by Serullas. As soon as arsenic comes in contact with bromine, it burns with a strong light, and the evolution of much heat, and a transparent colourless liquid is formed, which is the bromide in question. The best way of forming it is to put a quantity of bromine into a tubulated retort, and to throw into it pulverized arsenic by a little at a time, till it ceases to take fire. After each addition, the retort must be gently agitated. The combustion takes place like that of potassium on water. When the compound is formed it may be distilled over into a receiver, and thus freed from all excess of arsenic.

Bromide of arsenic becomes solid when cooled down to 68°, and it liquefies when raised to a temperature a few degrees higher. It boils and may be distilled over at 428°. Its colour has a very slight shade of yellow. On solidifying it crystallizes in long prisms. It absorbs moisture from the atmosphere. When mixed with water it is immediately decomposed into hydrobromic acid and arsenibus acid. It was subjected to analysis by Serullas. He has not given the particulars of his experiments, but only the general results. From which it appears that the compound is a sesquichloride, composed of

$1\frac{1}{2}$ atom bromine   .   .   15
1 atom arsenic   .   .   4·75

19·75

So that its atomic weight is 19·75.*

V. It appears, from the experiments of Plisson, that the best way of forming the iodide of arsenic is to mix together 3 parts of arsenic in fine powder, 10 parts of iodine, and 100 parts of water, and to digest this mixture till the smell of iodine disappears. The clear liquid is now decanted off, and subjected to evaporation. At a certain degree of concentration, red crystals of iodide of arsenic are deposited. To obtain the iodide in a state of purity, we must evaporate the liquid to dryness, and heat the dry mass that remains till it melts. After cooling, it has a brick red colour, and a crystalline texture. It is destitute of smell. When heated in close vessels, it melts and sublimes, and on cooling, it resumes its former appearance; but a portion of it is decomposed. In a large quantity of water it dissolves; but when mixed with a small quantity of water, that liquid undergoes decomposition; hydriodic acid and arsenious acid being formed.

* Ann. de Chim. et de Phys. xxxviii. 319.

This iodide has been subjected to analysis by Plisson, and there is reason to conclude from his experiments, that it is a sesquiodide, or a compound of

$1\frac{1}{2}$ atom iodine   .   .   23·625
1   atom arsenic   .   .   4·75

_____

28·375

So that its atomic weight is 28·375.*

VI. Fluoride of arsenic was obtained by Unverdorben. Fluoride. His method was to distil a mixture of fluor spar, arsenious acid, and sulphuric acid, in a leaden or platinum retort. A fuming colourless liquid passes over, which is the fluoride in question. This liquid smokes, and has a specific gravity of 2·73. When it comes in contact with water or glass, it is decomposed. In the first case, it is converted into fluoric acid and arsenious acid. It must therefore be a compound of

$1\frac{1}{2}$ atom fluorine   .   .   3·375
1   atom arsenic   .   .   4·75

_____

8·125

So that its atomic weight must be 8·125.†

VII. Arsenic combines with hydrogen and forms a com- Arsenietted pound, which has been called *arsenietted hydrogen gas.* hydrogen gas.

It was discovered by Scheele during his experiments on arsenic acid.‡ It was afterwards noticed by Proust during his experiments on tin.§ In the year 1803, an elaborate set of experiments on it was published by Tromsdorf.‖ In 1806, a very valuable set of experiments was made upon it by Professor Stromeyer.¶ It was examined in 1808 by Gay-Lussac and Thenard, during their experiments on potassium.** But the most important set of experiments on it hitherto published, are those of Dumas.††

It may be obtained by dissolving in muriatic acid an alloy of arsenic and tin, or an alloy of zinc and arsenic. Gehlen, who fell a victim to his experiment on this gas in 1815, prepared it by heating arsenic in an alkaline ley. Whatever

* Ann. de Chim. et de Phys. xxxix. 265.
† Berzelius's Chemistry, ii. 443.
‡ Scheele's Memoires de Chimie, i. 182.
§ Ann. de Chim. xxviii. 215.   ‖ Nicholson's Journal, vi. 200.
¶ Nicholson's Journal, xix. 381.
** Recherches Physico-chimiques, i. 229.
†† Ann. de Chim. et de Phys. xxxiii. 358.

method we employ to prepare it, we never obtain it pure.   It is always mixed with a very large proportion of hydrogen gas.

Its purity is easily determined by exposing it to the action of a saturated solution of sulphate of copper. The arsenietted hydrogen is absorbed and the hydrogen gas remains.   Dumas found that 100 volumes of the purest gas which he could procure was a mixture of

From 30 to 28 arsenietted hydrogen gas.

70 to 72 hydrogen gas.

Arsenietted hydrogen gas, thus formed, is colourless, has a nauseous smell, is not sensibly absorbed by water, extinguishes flame, and destroys animal life.   It burns with a blue flame; and if the neck of the vessel containing it be narrow, the arsenic is deposited.   When mixed with oxygen and brought in contact with a lighted taper, an explosion takes place, and water and arsenious acid are formed.   Arsenietted hydrogen gas is not altered by common air, azotic gas, nor hydrogen.   Nitrous gas occasions a diminution of about two per cent.   Sulphuretted hydrogen gas occasions no change in it; but if chlorine gas be added to the mixture of these two gases, the bulk diminishes, and yellow-coloured flakes are deposited.   Hence these two gases furnish us with a delicate test for detecting the presence of arsenietted hydrogen.   Concentrated nitric acid, when suddenly mixed with this gas, causes an evolution of red fumes, and an explosion accompanied with flame.

When tin is melted in this gas the arsenic is absorbed and the hydrogen set at liberty, as Gay-Lussac and Thenard first showed.   Dumas found that a volume of this gas when heated in this way left $1\frac{1}{2}$ volume of hydrogen gas.   He found that for complete combustion 1 volume of this gas requires $1\frac{1}{2}$ volume of oxygen.   The products are water and arsenious acid.   Now 1·5 volume of hydrogen require 0·75 volume of oxygen.   There remain for the arsenic 0·75 volume of oxygen; which is equivalent to an atom and a half.   There can be no doubt that the gas is a compound of

$1\frac{1}{2}$ volume of hydrogen gas, ⎱ condensed into 1 volume.

1   volume of arsenic vapour, ⎰ Hence we see that a volume of arsenic vapour, which is equivalent to an atom, requires for conversion into arsenious acid to combine with $1\frac{1}{2}$ atom of oxygen.

The specific gravity of arsenietted hydrogen gas, as determined by Dumas, is 2·695.   If we subtract from this gravity, 0·10416 ($1\frac{1}{2}$ volume hydrogen), the remainder 2·591 will

indicate the quantity of arsenic contained in a volume of the gas. The gas then is a compound of

$$
\begin{array}{lll}
\text{Hydrogen} & . & . & 0\cdot10416 \\
\text{Arsenic} & . & . & 2\cdot591
\end{array}
$$

Now these numbers are proportional to

$$
\begin{array}{lll}
\text{Hydrogen} & . & . & 0\cdot1875 \\
\text{Arsenic} & . & . & 4\cdot664
\end{array}
$$

The first of these numbers represents the weight of $1\frac{1}{2}$ atom hydrogen. The second 4·664, is the weight of an atom of arsenic. It is a little below the number 4·75, which I have pitched upon for the atomic weight of arsenic; owing doubtless to difficulty of determining the specific gravity of arsenietted hydrogen with perfect accuracy. The weight of a volume of arsenic vapour deduced from the atomic weight 4·75 is 2·6888. Consequently, if that weight be accurate, as I think it is, arsenietted hydrogen is a compound of

$$
\begin{array}{lll}
1\frac{1}{2} \text{ volume hydrogen gas} & . & . & 0\cdot10416 \\
1 \text{ volume arsenic vapour} & . & . & 2\cdot68888 \\
\hline
& & & 2\cdot79305
\end{array}
$$

And its true specific gravity must be 2·79305. This differs by about 4 per cent. from the experimental result of Dumas.

There is a solid compound of arsenic and hydrogen, which was first noticed by Ritter. It is obtained when a rod of arsenic is attached to the negative pole of a galvanic battery and plunged into water, while a wire from the positive pole plunges into the same liquid. The hydrogen of the water instead of being disengaged unites to the arsenic, and brown flocks are disengaged which constitute the hydret of arsenic in question. It may be collected and dried without alteration, and is not even decomposed though heated to a cherry red in azotic gas : but when heated in air or oxygen gas it catches fire, and water and arsenious acid are formed.

Hydret of arsenic.

VIII. Nothing is yet known respecting the combinations of arsenic with azote, carbon, boron, or silicon.

IX. Arsenic combines readily with phosphorus. The phosphuret of arsenic may be formed by distilling equal parts of its ingredients over a moderate fire. It is black and brilliant, and ought to be preserved in water. It may be formed likewise by putting equal parts of phosphorus and arsenic into a

Phosphuret.

sufficient quantity of water, and keeping the mixture mode-
rately hot for some time.*

Sulphuret.   X. Sulphur and arsenic unite in different proportions.
Four different sulphurets of arsenic are known, and have been
accurately analyzed.

Realgar.   1. Sulphuret or *realgar*.   If we put a mixture of these two
bodies into a covered crucible and melt them, a red vitreous
mass is obtained, which is obviously a sulphuret of arsenic.
It may be formed also by heating together arsenious or arsenic
acid and sulphur; but in that case a portion of the sulphur
absorbs the oxygen from the arsenic, and makes its escape in
the form of sulphurous acid gas.† This sulphuret of arsenic
is found native in different parts of Europe.   It is usually
called *realgar*.   It has a scarlet colour, and is often crystallized
in transparent prisms.   Its specific gravity is 3·3384.‡   It is
tasteless and not nearly so hurtful as the oxides of arsenic,
though Macquer affirms that it is poisonous.§   It is sometimes
used as a paint.

This sulphuret, according to the experiments of Berzelius,
is composed of

Arsenic	.	.	100
Sulphur	.	.	42·85

Now 42·85 is to 100 as 2 to 4·667.   These two numbers are
so near the atomic weights of the two bodies, that we can have
no doubt that realgar is a compound of

1 atom sulphur	.	.	2
1 atom arsenic	.	.	4·75
			6·75

and that its atomic weight is 6·75.

When 24 parts of nitre, 7 of flowers of sulphur, and 2 of
realgar, are triturated together, they form a mixture which burns
with an exceedingly white flame and great splendour.   It is
known by the name of white Indian fire, and is occasionally
used in fire-works and in theatres when a very splendid
combustion is wanted.

Sesquisulphu-   2. *Sesquisulphuret of arsenic* or *orpiment*.   If arsenious acid
ret.   be dissolved in muriatic acid, and a solution of sulphuretted
hydrogen in water be poured into the liquid, a fine yellow-

* Pelletier, Ann. de Chim. xiii. 139.
† Proust; Jour. de Phys. liii. 94.   ‡ Haüy's Mineralogie, iv. 228.
§ Hoffman informs us, that he gave two scruples of it to a dog without
any bad effects whatever.   Observ. Physico-Chemico-Select. p. 236.

coloured powder falls to the bottom. This powder is usually
called *orpiment.* It may be formed by subliming arsenic and
sulphur by a heat not sufficient to melt them. This substance
is found native. It is composed of thin plates, which have a
considerable degree of flexibility. Its specific gravity is
3·4522.* It has been supposed by some chemists, that orpi-
ment differs from realgar merely in containing a smaller pro-
portion of sulphur; by others, that the arsenic exists in it in
the state of an oxide; by others, that it contains sulphuretted
hydrogen. But Mr. Proust has ascertained, that when heated
sufficiently it melts without emitting any gas, and on cooling
assumes the appearance of realgar.† Haüy observed that the
figure of their crystals is the same. Hence he was led to
consider them as different forms of the same substance, con-
formably to the opinion of Proust.‡ This induced Laugier to
make a set of experiments to elucidate the subject.§ The
result of his experiments was that sulphuret of arsenic, artifi-
cially prepared, is composed of

Arsenic	. .	$58\frac{1}{3}$	. .	100
Sulphur	. .	$41\frac{2}{3}$	. .	71·42

But Berzelius has shown that the experiments of Laugier were
inaccurate in many respects. It follows from the observations
of Berzelius that orpiment is a compound of

Arsenic	. .	61
Sulphur	. .	39

Now 39 is to 61 as 3 ($1\frac{1}{2}$ atom sulphur) to 4·692, which is
very nearly an atom of arsenic. It is evident from this that
orpiment is a compound of

$1\frac{1}{2}$ atom sulphur	. .	3
1 atom arsenic	. .	4·75

7·75

and that its atomic weight is 7·75.

3. *Sulphide of arsenic.*‖ When a current of sulphuretted Sulphide.
hydrogen gas is passed through a moderately concentrated solu-
tion of arsenic acid in water a yellow coloured precipitate falls,

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* Haüy, iv. 235.   † Jour. de Phys. liii. 94.
‡ Ann. de Chim. lxxxv. 36.   § Ibid.
‖ I adopt this name of Berzelius for want of a better to distinguish this
compound from the preceding. But in the subsequent part of this work I
shall use the term *sulphide* to denote those compounds of sulphur and a
base which possess acid properties. All the compounds of sulphur and
arsenic are in reality *sulphides.*

very much resembling orpiment in appearance.   The nature of this precipitate was first recognised by Berzelius.   It is much less fusible than sulphur, and when fused its colour becomes deeper and reddish. . It sublimes unaltered and forms a brownish red mass not the least crystalline in its texture. When boiled with alcohol a little sulphur is dissolved, which crystallizes as the liquid cools.   It reddens tincture of litmus when boiled with it; but the blue colour returns when the liquid cools.   The alkaline hydrates and concentrated ammonia dissolve it.   It decomposes the hydrosulphurets and the carbonates.   According to the analysis of Berzelius it is composed of

<div align="center">

Arsenic   .   .   100
Sulphur   .   .   106·91

</div>

Now 100 is to 106·91 as 4·75 to 5·078.   But 5·078 is almost exactly $2\frac{1}{2}$ atoms of sulphur.   It is obvious from this that the sulphide of arsenic is a compound of

<div align="center">

1   atom arsenic   .   .   4·75
$2\frac{1}{2}$ atoms sulphur   .   .   5
                                            ―――――
                                            9·75

</div>

and that its atomic weight is 9·75.

Persulphuret.   4. *Persulphuret of arsenic.* This compound was also discovered by Berzelius.   It may be obtained by precipitating a neutral solution of sulpharseniate of potash or soda by means of alcohol, filtering the liquid and distilling off the half, or at most two-thirds of the alcohol.   When the residual liquid is allowed to cool it deposites groups of yellow brilliant crystals, exceedingly bulky and light.   With these crystals are mixed small particles of an alkaline sulphuret.   This persulphuret, according to the analysis of Berzelius, is composed of

<div align="center">

Arsenic   .   .   20·61
Sulphur   .   .   79·39
                           ―――――
                           100*

</div>

Now 20·61 is to 79·39 as 4·75 to 18·29.   And 18·29 comes very near the weight of 9 atoms of sulphur.   It is clear from this that persulphuret of arsenic is a compound of

<div align="center">

1 atom arsenic   .   .   4·75
9 atoms sulphur   .   .   18
                                    ―――――
                                    22·75

</div>

* Chemistry, ii. 440.

Its atomic weight is 22·75, and it contains just twice as much sulphur as the sulphide.

XI. Selenium, when in a state of fusion, dissolves arsenic by degrees. The excess of either body sublimes if the heat be continued, and we obtain the seleniet of arsenic in the state of a black and very fusible mass. When heated to redness, it boils, and a portion sublimes, which Berzelius considers as a biseleniet of arsenic. The boiling soon terminates, and the matter remains in a red heat, without any agitation. At a white heat it distils over in drops. When cold, it has a blackish brown colour. It has a vitreous fracture.*

SECTION XI.—OF ANTIMONY.

The ancients were acquainted with an oxide of antimony to which they gave the names of διμμι and *stibium*. Pliny† informs us, that it was found in silver ore ; and we know that at present there are silver ores‡ in which it is contained. It was used as an external application to sore eyes; and Pliny gives us the method of preparing it.§ It is probable that a dark bluish grey mineral, of a metallic lustre, was also known to them by the same names. It certainly bore these names as early at least as the eighth century. This mineral is composed of the metal now called *antimony* and sulphur; but it was known by the name of *antimony* ever since the days of Basil Valentine till very lately. The metal itself, after it was discovered, was denominated *regulus of antimony.* The Asiatic‖ and Grecian ladies employed this mineral to paint their eyebrows black. But it does not appear that the ancients considered this substance as containing a metal, or that they knew our antimony in a state of purity.¶ Who first extracted it from its ore we do not know; but Basil Valentine is the first who describes the process. To his *Currus Triumphalis Antimonii*, published towards the end of the fifteenth century, and to the exertions of those medical alchymists who followed his career, we are indebted for almost all the properties of this substance yet known.

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* Berzelius, Ann. de Chim. et de Phys. ix. 250.
† Pliny, lib. xxxiii. cap. 6.   ‡ Kirwan's Miner. ii. 110.
§ Pliny, lib. xxxiii. cap. 6.   ‖ 2 Kings, ix. 30, and Ezek. xxiii. 40.
¶ Mr. Roux, indeed, who at the request of Count Caylus analyzed an ancient mirror, found it composed of copper, lead, and antimony. This would go far to convince us that the ancients knew this metal, provided it could be proved that the mirror was *really* an ancient one; but this point appears to be extremely doubtful.

No metal, not even mercury nor iron, has attracted so much of the attention of physicians as antimony. One party extolled it as an infallible specific for every disease: while another decried it as a most virulent poison, which ought to be expunged from the list of medicines. Lemeri, about the end of the 17th century, was the first chemist who attempted a rational account of its properties; and Meuder, in 1788, published the first tolerably accurate analysis of its ores.* But the number of writers who have made this metal their particular study is so great, that it would be in vain to attempt even a list of their names. Bergman, Berthollet, Thenard, Proust, and Berzelius, are the modern chemists who have thrown the greatest light upon its properties.†

Antimony, as it is met with in commerce, is never quite pure; but it may be purified by the following process: Reduce it to a fine powder, and mix it with its own weight of antimonic acid, and fuse it in a crucible. The impurities are all oxydized and separated by the oxygen of the antimonic acid, and the metal remains in a state of purity.

Properties.

Pure antimony has a silver white colour and a good deal of lustre. Its texture is fibrous, or perhaps composed of very fine plates; but it does not present the broad laminated texture of the antimony of commerce. It is easily crystallized by fusion and slow cooling. The primary form of its crystals is the octahedron. It is quite brittle and easily reduced to powder in a mortar. Its specific gravity, as determined by me, is 6·4366. Mr. Hatchett found that of the antimony of commerce 6·712. Brisson states it at 6·702, and Bergman at 6·86. According to the experiments of Dr. Cromwell Mortimer, it melts at 810°; or just when heated to redness.‡ When heated to whiteness by the blowpipe, and thrown upon the table, it burns for some time with great splendour, giving out a white smoke, and rolling about upon the table. It par-

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* Analysis Antimonii Physico-chim. Rationalis.

† The word *alcohol*, which is still employed in chemistry, was, if we believe Homerus Poppius Thallinus, first applied to this mineral. " Hispanicis mulierculis ejus usus in ciliorum pulchritudine concilianda fuit usitatissimus : pulverem autem vocabant alcohol (quæ vox etiam adhuc in Hermeticorum laboratoriis sonat); unde antimonium crudum et nondum contusum piedra de alcohol nominarunt." It was known among the alchymists by a great variety of absurd names; such as Othia, alkofol, alkosol, aries, Saturnus philosophorum, magnesia Saturni, filius et nothus Saturni.

‡ Phil. Trans. 1747, p. 672.

ticipates this property with tin and bismuth. At a white heat it may be distilled over.

II. When exposed to the air, it undergoes no change except the loss of its lustre. Neither is it altered by being kept under water. But when steam is made to pass over red-hot antimony, it is decomposed so rapidly, that a violent detonation is the consequence.*

When heated in an open vessel, it gradually combines with oxygen, and evaporates in a white vapour. This vapour, when collected, constitutes a white coloured oxide, formerly called *argentine flowers of antimony*. When raised to a white heat, and suddenly agitated, antimony burns, and is converted into the same white coloured oxide.

The oxides of antimony have been investigated with con- Oxides. siderable care by Thenard,† Proust,‡ Bucholz, and Berzelius.§ According to Thenard, this metal forms no fewer than six oxides; according to Proust and Bucholz, whose researches coincide with those of Proust, it forms only two : while according to Berzelius it is capable of forming four oxides. The protoxide of Berzelius was obtained by exposing antimony to the air or to the action of the galvanic battery. It was a grey powder. When acted on by muriatic acid it was separated into the protoxide of Proust and metallic antimony. Hence it is probably merely a mixture of the two. The two oxides of Proust are easily obtained and possess specific characters. Berzelius has shown that the second of them possesses the properties of an acid. The peroxide of Berzelius is also readily obtained; though it is not easily freed from water. It likewise possesses the properties of an acid. We know therefore three compounds of antimony and oxygen. The *oxide* is *grey*, *antimonious acid* is *white*, and *antimonic acid* is *straw yellow*.

1. The oxide of antimony may be obtained by the fol- Protoxide. lowing process. Dissolve antimony in muriatic acid, and dilute the solution with water : a white precipitate appears, composed of the protoxide of antimony combined with a little muriatic acid.‖ Wash this precipitate with water, and boil it for some

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* Lavoisier and Meusnier, Mem. Par. 1781, p. 274.

† Ann. de Chim. xxxii. 259.   ‡ Jour. de Phys. lv. 328.

§ Nicholson's Journal, xxxiv. 241, 343, and xxxv. 38.—Annals of Philosophy, iii. 248.

‖ The white powder thus obtained was formerly called *powder* of Algaroth, from Victor Algarothi, a physician in Verona, who first procured it in that manner from muriate of antimony.

time in a solution of *carbonate of potash.* Then wash it well, and dry it on a filter.*

According to Berzelius, it may be obtained also by oxydizing antimony by means of nitric acid, and washing the matter formed with water, till it ceases to redden litmus paper. It is then to be dried.

Properties.
Oxide of antimony has usually a dirty white colour. When obtained by sublimation, or in the state known by the name of argentine flowers of antimony, it has a white colour and a beautiful silky lustre. When heated it assumes a yellow colour. When rapidly heated to redness in an open vessel, it glows like tinder, and is converted into antimonious acid. When heated to redness in a retort, it melts and forms a yellow coloured liquid, which crystallizes on cooling, and assumes a pearl grey colour. It may be sublimed or distilled over at a red heat, in vessels freed from air or oxygen gas. By this easy fusibility and volatility, it is readily distinguished from the other oxides of antimony. This oxide enters as a base into the compound salt called *tartar emetic.* But with this exception it seems rather to possess the character of an acid than a base. For it combines with potash, soda, and ammonia, and forms with them crystalline salts, little soluble in water. This oxide dissolves very readily in muriatic acid.

Glass of antimony.
What is called *glass of antimony,* is nothing more than this oxide combined with some sulphuret of antimony, and some silica derived from the crucible. It is prepared by roasting sulphuret of antimony in powder, till the greatest part of the sulphur is driven off. The residue is then fused in a clay crucible. This glass is usually employed for the manufacture of tartar emetic. The whole process consists in boiling this glass reduced to a fine powder with cream of tartar and water, drawing off the liquid from the undissolved portion, and setting it aside to crystallize. Care should be taken that the boiling is continued long enough to saturate the bitartrate of potash with oxide of antimony.

Glass of antimony has a brownish yellow colour, a certain degree of transparency, a glassy fracture, and it is quite tasteless. When the proportion of sulphuret of antimony is considerable, the *glass* is opaque and of a liver colour. It is then called *liver of antimony.*

Antimonious acid.
2. Antimonious acid is easily obtained by oxydizing anti-

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* Proust, Jour. de Phys. lv. 328.

~mony by means of nitric acid evaporating to dryness, and exposing the residual matter to a red heat. It has a fine white colour; but becomes yellow when heated. It cannot be fused nor sublimed at a red heat; nor indeed does it undergo any alteration by exposure to a strong heat; except that it becomes less easily acted on by acids or bases.

It is not nearly so easily reduced to the metallic state when heated with charcoal as *oxide* of antimony. Heated before the blowpipe in the interior flame, it evaporates without leaving any metallic button. When heated with a mixture of charcoal and potash, it may be obtained in the metallic state. When fused with potash or its carbonate, a compound is formed which dissolves in water, from which the antimonious acid is precipitated by the addition of water in the state of an hydrate. According to the experiments of Berzelius, it is a compound of 94·74 antimonious acid and 5·26 water. It will appear immediately that it is a compound of 3 atoms antimonious acid, and 1 atom water; or it is a trishydrate of antimonious acid.

This hydrate is soluble in muriatic acid, though the anhydrous antimonious acid dissolves only exceedingly slowly. When the solution is diluted with water, the antimonious acid precipitates after a certain time.

Berzelius found that 100 parts of pure antimony, when converted into antimonious acid, give 124·8 parts of that acid.* Hence antimonious acid is a compound of

Antimony	.	:	100
Oxygen	.	.	24·8

He found also that when 124·8 parts of antimonious acid are mixed with 33⅓ parts of antimony, the whole is converted into oxide of antimony, weighing 158·13.† It is obvious from these experiments, that oxide of antimony is a compound of 133⅓ antimony, and 24·8 oxygen; while antimonious acid is a compound of 100 antimony, and 24·8 oxygen, or, in other words, we have the constituents of these bodies as follows:

	Antimony.	Oxygen.
Oxide of antimony . .	100 +	18·6
Antimonious acid . .	100 +	24·8

Now the numbers 18·6 and 24·8 are to each other as 3 to 4. If therefore we consider oxide of antimony as a compound of 1 atom antimony, and 1 atom oxygen, it is clear that antimo-

nious acid must be a compound of 1 atom antimony, and 1½ atom oxygen; and the atom of antimony will be 5·375.

3. Antimonic acid may be obtained by dissolving antimony in aqua regia, evaporating the solution to dryness, adding nitric acid to the residue, and heating it till all the nitric acid is expelled. We, must beware of raising the temperature to redness, otherwise the antimonic acid will lose oxygen, and be converted into antimonious acid.

Antimonic
acid.

Antimonic acid is obtained also, when antimony in powder is mixed with six times its weight of nitre and exposed for an hour in a silver crucible to as strong a heat as the crucible can bear. The potash and nitre are then to be washed off with water. The white powder remaining is to be digested for a long time in muriatic acid to deprive it of the potash which it contains. It is then to be dried and exposed to a heat sufficiently strong to drive off the water with which the oxide still continues united.

It is a straw coloured powder, tasteless and insoluble in water. When digested with the alkaline carbonates in solution in water, it does not decompose them; but when heated together with them in a crucible, the carbonic acid is driven off, and antimoniates formed. It dissolves in boiling caustic potash. The acids precipitate from this solution a white powder, which is a hydrated antimonic acid. This hydrate reddens litmus paper, and dissolves both in muriatic acid and in caustic alkaline leys. When the muriatic acid solution is diluted with a little water, the antimonic acid gradually precipitates; but, according to L. Gmelin, if it be mixed at once with a considerable quantity of water, no precipitate appears. This is not the case with the muriatic solution of antimonious acid.

When this hydrate is heated, 100 parts of it give out 5·09 parts of water. The anhydrous acid assumes a yellow colour, and loses the property of reddening litmus paper. When antimonic acid is heated to redness, it gives out oxygen, and is converted into antimonious acid.

I found that 5½ parts of antimony, when converted into antimonic acid, become 7½ parts, and that when 100 grains of antimonic acid were heated to redness, they gave out above 18 cubic inches of oxygen gas. I found also that 7½ parts of antimonic acid, when converted into antimonious acid, weighed 7 parts.*

* Annals of Philosophy (2d series), ii. 124.

But Berzelius, who resumed the investigation of these oxides after the appearance of my experiments, found that 100 parts of antimony, when united with oxygen, and converted into antimonic acid, weighed only 131 parts; while, in my trials, the increase was from 100 to 136·3. I do not know on what this difference in our results can depend, unless I had not sufficiently dried my antimonic acid to expel the whole water and nitric acid. The difference on the scale on which my experiments were made, would have amounted almost to 0·3 grain, a difference which could not have escaped detection.

The remarkable analogy between arsenic and antimony (which Rose has shewn to be isomorphous bodies) induces me to consider the result of Berzelius as the correct one. For if 100 antimony to form oxide combines with 18·6 oxygen, and to form antimonic acid with 31 oxygen, then the constitution of oxide of antimony, and antimonic acid, will be precisely the same as that of arsenious and arsenic acid. For 18·6 is to 31 exactly as 3 to 5.

But if we confide in the analysis of Berzelius, the oxygen in the oxides of antimony is as the numbers 3, 4, and 5. How, then, shall we view the composition of these oxides? If the oxide be a compound of 1 atom antimony, and 1 atom oxygen, then the composition would be

	Antimony.	Oxygen.	Atomic weight.
1 Oxide . . .	1 atom	+ 1 atom	6·375
2 Antimonious acid .	1	+ $1\frac{1}{3}$	6·708
3 Antimonic acid . . 1		+ $1\frac{2}{3}$	7·041

Numbers so exceedingly complicated, that they can never represent the real constitution of these bodies.

If, in consequence of the analogy between arsenic and antimony, we consider the oxide as a compound of $1\frac{1}{2}$ atom oxygen, and the antimonic acid of $2\frac{1}{2}$ atoms oxygen, with an atom of antimony, then the atom of antimony will become 8, and we shall have the constitution of these oxides as follows: Constitution of the oxides.

	Antimony.	Oxygen.	Atomic weight.
1 Oxide . . .	1 atom	+ 1·5 atom	9·5
2 Antimonious acid .	1	+ 2	10·
3 Antimonic acid .	1	+ 2·5	10·5

This is a much simpler view of the subject; and as it preserves the analogy between antimony and arsenic, I am disposed to adopt it. We might get rid of the anomaly of the $2\frac{1}{2}$ atoms of oxygen in antimonic acid, by considering it as a compound of two atoms of antimonious acid, and 1 atom of oxygen. This

would make its atomic weight 21. Now Berzelius found anti-
moniate of potash a compound of

Antimonic acid . .	22·8
Potash . .	6
	28·8*

Which rather corroborated this way of viewing the acid. For
6 is the atomic weight of potash, and 22·8 approaches 21,
the atomic weight of antimonic acid on our supposition. I am
therefore disposed to consider the atomic weight of antimonic
acid as 21.

He found antimonite of potash a compound of

Antimonious acid . .	19·6
Potash	6
	25·6

Now as there is no reason for considering the atom of anti-
monious acid any thing but 10, this salt must have been a
binantimonite. So also may be the antimoniate analyzed.
We have therefore no satisfactory evidence from these analyses
of the atomic weight of antimonic acid.

Chlorides.   III. So far as we know at present, chlorine and antimony
combine only in two proportions, and form two chlorides,
analogous to the oxide of antimony and antimonic acid.†

Sesquichlo-   1. It has been long known that when a mixture of 2 parts
ride.
of corrosive sublimate and 1 part of antimony is distilled, a
fatty mass of a greyish white colour comes over, often crystal-
lized in four-sided prisms. This substance was formerly dis-
tinguished by the name of *butter of antimony.* It melts at a
moderate heat, is very volatile, and is decomposed when mixed
with water into hydrochloric acid and oxide of antimony, with-
out any trace of antimonious or antimonic acid. It is obvious
from this, that it is a sesquichloride, or compound of

1½ atom chlorine . .	6.75
1 atom antimony . .	8
	14·75

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* Ann. de Chim. lxxxvi. 242.

† I described, in my "First Principles," another chloride, which I called
dichloride of antimony. But I have since found that it contained a notable
quantity of chloride of lead. It was only therefore a mixture of chlorides
of lead and antimony.

So that its atomic weight is 14·75. It was subjected to an analysis by M. H. Rose, who obtained

Chlorine	.	.	46·73
Antimony	.	.	53·27
			――――――
			100·00*

The chlorine was a little in excess, because the chloride of silver, from which it was deduced, was not quite free from sulphuret of silver. But these numbers give us,

Chlorine	.	.	7
Antimony	.	.	8

The excess of chlorine amounts only to $\frac{1}{27}$th part.

2. The other chloride is obtained by passing a current of Perchloride. dry chlorine gas over heated metallic antimony. The antimony burns vividly in the gas, emitting sparks, while, at the same time, a volatile liquid is formed, which is the chloride. It is a white liquid, or having only a light yellowish tinge. If the antimony contains iron (as is frequently the case), chloride of iron is also formed, and mixed with this liquid; but the chloride of iron is left behind when the liquid chloride, which we shall call *perchloride of antimony*, is distilled over.

The perchloride of antimony has a strong and disagreeable smell, and fumes in the atmosphere. Exposed to the air, it attracts moisture, and is converted into a white mass, in which crystals form. These crystals afterwards dissolve without rendering the solution milky. The reason is, that this perchloride, when united to a certain quantity of water, forms solid crystals. When mixed with water, it is decomposed and converted into antimonic acid, and muriatic acid. It is obvious from this, that it is a compound of

$2\frac{1}{2}$ atoms chlorine	.	.	11·25
1 atom antimony	.	.	8
			――――――
			19·25

M. H. Rose subjected it to analysis, and obtained

Chlorine	.	.	59·44
Antimony	.	.	40·56
			――――――
			100†

Now this is equivalent to

---

* Ann. de Chim. et de Phys. xxix. 243. † Ibid. p. 245.

Chlorine . . 11·72
Antimony . . 8

In this analysis also the quantity of chlorine obtained, exceeds the truth, owing to the presence of a little sulphuret of silver in the chloride, from which the chloride was deduced.

Thus these chlorides are quite analogous in their constitution to oxide of antimony and antimonic acid. No chloride analogous to antimonious acid has been detected.

Sesquibromide.

IV. Only one combination of antimony and bromide has been yet formed; it is a *sesquibromide* analogous to oxide of antimony. For our knowledge of it, we are indebted to M. Serullas.*

It may be formed by putting some bromine into a tubulated retort, and throwing on it antimony in powder as long as that metal continues to take fire. It is then to be distilled over into the receiver. It is much less fusible and volatile than the sesquibromide of arsenic. It melts at about the temperature of 200°, and boils at 518°. It is colourless and crystallizes in needles. It attracts moisture from the atmosphere. When mixed with water, it is decomposed into oxide of antimony and hydrobromic acid. From this it is obvious that it is a compound of

$1\frac{1}{2}$ atom bromine . . 15
1 atom antimony . . 8
——
23

Serullas analyzed it, and verified this constitution.

Sesquiodide.

V. Antimony unites readily to iodine when the two substances are heated together, and the excess of iodine is easily driven off. The iodide is a dark red solid, which melts readily when heated, and which, when put into water, is converted into oxide of antimony and hydriodic acid. From this, it is evident that it is a sesquiodide, or a compound of

$1\frac{1}{2}$ atom iodine . . 23·625
1 atom antimony . . 8
——
31·625

The iodide analogous to antimonic acid, or the periodide, as it would be called, has not been yet formed.

Fluoride.

VI. Dumas has formed a fluoride of antimony, which he describes as snow-white, more volatile than sulphuric acid, but less so than water. It is a compound, he informs us, of

* Ann. de Chim. et de Phys. xxxviii. 322.

1½ atom fluorine	.	.	3·375
1 atom antimony	.	.	8
			11·375

It is therefore a sesquifluoride analogous to oxide of antimony, and the other first compounds of antimony with a supporter.*

VII. We are not acquainted with any combinations which antimony forms with hydrogen, azote, carbon, boron, or silicon.

VIII. When equal parts of antimony and phosphoric glass are mixed together with a little charcoal powder, and melted in a crucible, phosphuret of antimony is produced. It is of a white colour, brittle, appears laminated when broken, and at the fracture a number of small cubic facettes are observable. When melted it emits a green flame, and the white oxide of antimony sublimes. Phosphuret of antimony may likewise be prepared by fusing equal parts of antimony and phosphoric glass, or by dropping phosphorus into melted antimony.† Phosphuret.

IX. Sulphur and antimony combine in three proportions, and form three sulphurets, quite analogous in composition to the oxides of antimony. Sulphides.

1. The sesquisulphuret of antimony is found native, and is met with in commerce, in the shape of cones, under the name of crude antimony. It is obtained in this state by putting the ore into a crucible, having a hole in its bottom, and placed over another crucible of the same size. A fire is kindled round the upper crucible; the sulphuret melts and runs into the under crucible, and forms a cone, while the earthy and stony matter remains in the upper crucible. This sulphuret is almost always contaminated with sulphuret of lead and sulphuret of iron; sometimes, it is said, with sulphuret of arsenic. Sesquisulphide.

Pure sesquisulphuret of antimony has a bluish-grey colour, and the metallic lustre, a foliated or striated texture, a specific gravity of 4·62, and is much more fusible than antimony; boils at a high temperature, and may be distilled over in close vessels without decomposition. It dissolves completely in muriatic acid when assisted by heat, and is converted into oxide of antimony and sulphuretted hydrogen gas. It is obvious from this, that it is a compound of

* Ann. de Chim. et de Phys. xxxi. 435.
† Pelletier, Ann. de Chim. xiii. 132.

$1\frac{1}{2}$ atom sulphur . . 3
1 atom antimony . . 8
___
11

It has been often analyzed, and the analysis which comes nearest the truth is that of Berzelius, who found it a compound of

Antimony . . 100
Sulphur . . 37

The theoretic quantity of sulphur united to 100 antimony is 37·5. I obtained 35·572. All the other analyses are still below this quantity.

When this sesquisulphuret is pure, its powder has a reddish brown colour. This compound possesses acid properties, and ought therefore to be considered as a *sulphide*. It may be obtained by passing a current of sulphuretted hydrogen gas through a solution containing oxide of antimony, for example, through a solution of tartar emetic. In that case, it is in flocks of a fine orange red colour, but which assumes a dark red colour when dried. When this matter is heated, it gives out water, and assumes a black colour. It then possesses all the characters of sesquisulphuret of antimony.

Kermes mineral.
What is called *hermes mineral* is nothing else than a hydrated sesquisulphide of antimony mixed with a small quantity of antimonite of potash. Sesquisulphuret of antimony dissolves in caustic alkaline leys, and in solutions of the alkaline hydrosulphurets; but it dissolves much more copiously in these liquids when boiling hot. As the solution cools a brick red precipitate falls, which is quite the same as *kermes*. The preparation of kermes for medical purposes is thus performed.

Formation of.
1 part of carbonate of potash and $2\frac{2}{3}$ parts of sulphuret of antimony in powder are mixed together and heated gradually in a covered crucible till the whole is brought into a state of fusion. During this process a portion of the antimony is oxidized at the expense of the alkali. Sulphuret of potassium is formed together with some antimonite of potash, and also a compound of oxide and sulphuret of antimony which occurs native, and is known by the name of red antimony.*

The sesquisulphide of antimony combines with this sulphuret of potassium, constituting a sulphur salt composed of three

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* The nature of this compound will be explained in a subsequent part of this section.

atoms sesquisulphide, united to one atom of sulphuret. This salt solidifies into a brown matter called *liver of sulphur.* Water decomposes this salt and takes up the sulphuret of potassium, which dissolves a quantity of the sesquisulphide of antimony, and the quantity dissolved is much increased by boiling the liquid. The liquid is filtered while boiling hot. As it cools it deposites the kermes, under the form of light brown flocks, which are collected, washed, and dried. If the liquid from which the kermes fell be boiled again with the undissolved portion, and filtered while boiling hot, a new portion of kermes falls; and this process may be continued till nothing remains but oxide of antimony and sesquisulphide, which of course is quite insoluble in water.

Fabroni, junior, has given a process for preparing kermes, *Another process.* which he says is cheaper than the common one, and as it shows clearly that kermes contains no oxygen, it may be worth while to mention it here. Mix together three parts of crude tartar and 1 part of crude antimony, and heat the mixture in a crucible till it ceases to give out any smoke. Pulverize this mass and boil it in water, proceeding exactly as in the usual way of preparing *kermes.* The kermes precipitates in the usual way. Here the potash is converted into potassium by the action of the charcoal of the tartaric acid, so that no oxide of antimony is formed.

If we pour a little acid into the liquid from which the kermes *Sulphur auratum.* has precipitated, an additional portion of kermes is thrown down. If we now filter the liquor and add an additional portion of acid, we obtain a new precipitate of a fine orange red colour, and formerly known under the name of *sulphur auratum* or *golden sulphur.* It is usually prepared by mixing together equal weights of sulphur and crude antimony in powder, and boiling the mixture in a caustic alkaline ley till the whole is dissolved. Then sulphuric acid is added to throw down the sulphur auratum. Berzelius assures us that this sulphur auratum is nothing else than a bisulphide of antimony. If so, it is a compound of 4 parts of sulphur and 8 of antimony. But H. Rose subjected it to analysis and found it to be the persulphide of antimony.[*]

These preparations were at one time much employed in medicine. The method of preparing kermes was first discovered

[*] Ann. de Chim. et de Phys. xxix. 249.

Chap. II.

by Glauber, and afterwards by Lemery the elder; but it was first brought into vogue in France by a priest called Simon, who was taught the secret of preparing it by La Ligerie, a surgeon, to whom it had been communicated by a pupil of Glauber. The French government purchased the secret from La Ligerie, and published the process in 1720. It was very tedious and ill contrived, consisting in boiling repeatedly a very diluted solution of potash on sulphuret of antimony; a small portion of kermes precipitated as the solution cooled. The process of Lemery was therefore adopted by apothecaries.

Neither of these preparations are at present used by practitioners in Great Britain. From the few trials that I have made with kermes it appears to be a much more active medicine than crude antimony, and I should think it far preferable for every purpose to the *pulvis antimonialis* of our pharmacopœias, which in most cases is quite inert. The dose varies from half a grain to a grain. In larger doses it will act as an emetic. I have never tried the sulphur auratum; but the usual dose of it given in Germany, where it is still employed, is one grain. It is said to produce diaphoretic effects, and is administered in catarrhs and rheumatism.

Bisulphide.

2. Bisulphide of antimony was first described by M. H. Rose, who formed it by passing a current of sulphuretted hydrogen through a solution of antimonious acid or antimonite of potash in muriatic acid. No tartaric acid should be added to enable us to dilute the solution, otherwise the nature of the precipitate is altered. Its colour is orange red. When heated it gives off sulphur, and is converted into common sesquisulphide of antimony. M. H. Rose analyzed it by passing dry hydrogen through it while heated in a tube. By this means it was resolved into sulphuretted hydrogen and metallic antimony. The quantity of antimony enabled him to calculate the composition. Two separate analyses gave him the following results.

Sulphur	.	.	33·86	. .	33·45
Antimony	.	.	66·14	. .	66·55
			100		100*

It is evident from these analyses that the true composition is

* Ann. de Chim. et de Phys. xxix. 248.

2 atoms sulphur	.	.	4
1 atom antimony	.	.	8
			—
			12

and that its atomic weight is 12.

3. Persulphide of antimony may be obtained by passing a Persulphide. current of sulphuretted hydrogen through perchloride of antimony, to which tartaric acid has been added to prevent the antimony from precipitating when the liquid is diluted with water, as it must be before the sulphuretted hydrogen gas is passed through it. It may be easily obtained by fusing together 4 parts of carbonate of potash, 5 parts of crude antimony, and 1 part of sulphur. The fused mass is to be dissolved in boiling water, and precipitated by dilute sulphuric acid. It has a paler colour than bisulphide of antimony, and its colour does not change on drying.

Rose analyzed it by passing a current of dry hydrogen gas over it while hot. The sulphur was carried off and the metallic antimony remained. He dissolved another portion of it in aqua regia containing tartaric acid. The undissolved sulphur was separated and weighed, and the sulphuric acid formed during the solution, was thrown down by muriate of barytes and its quantity determined. These two processes gave him the antimony and the sulphur. He found it a compound of

$2\frac{1}{2}$ atoms sulphur	.	.	5
1 atom antimony	.	.	8
			—-
			13*

Hence its atomic weight is 13.

4. Sesquisulphide of antimony has the property of combin- Red antimony. ing with oxide of antimony, and of forming a compound which occurs native, and has been distinguished in Germany by the name of *rothspiesglanzerz*, and in this country by that of *red antimony*. Haüy calls it *antimoine hydro-sulphure*.† It usually occurs in small crystals on the surface of stones, and has been most commonly found at Braunsdorf in Saxony, and at Allemont in Dauphiny. Its colour is cherry red. It is crystallized in right square prisms, and has a specific gravity of 4·5. It is feebly translucent and sometimes has an adamantine lustre.

It was analyzed by M. H. Rose by passing a current of hydrogen gas over it while hot. By this means the sulphur

* Ann. de Chim. et de Phys. xxix. 249.   † Traité, iv. 276.

and oxygen was removed and metallic antimony left.   In one experiment 14 grains of the ore gave 10·4 grains of antimony, and the water collected by passing the sulphuretted hydrogen through dry chloride of calcium was 0·84 grains.   In another 15·1 grains gave 11·4 gr. of antimony and 0·73 grain of water. He then dissolved 5·24 grains of the mineral in aqua regia, adding tartaric acid, and precipitated by chloride of barium. He obtained 8 grains of sulphate of barytes.   These numbers are equivalent to

Antimony	. .	75·05
Oxygen	. .	4·78
Sulphur	. .	20·47
		100·30*

These numbers give us very nearly

Oxide of antimony . . .	.	30·28
Sesquisulphide of antimony	. .	70·05
		100·33

Now this comes sufficiently near

1 atom oxide of antimony	. .	9·5
2 atoms sesquisulphide	. .	22
		31·5

to leave no doubt that this is the true constitution of the mineral.

Iodesesqui-
sulphide.
    5. The sesquisulphide of antimony has the property, according to the experiments of M. Henry, junior, and Garot, to combine with iodine.   The two substances are mixed together in equal weights put into a glass mattrass, and sublimed by a gentle heat.   Red vapours are formed which condense in the upper part of the mattrass in brilliant scales, having a poppy red colour, and being transparent.   They melt and may be sublimed without decomposition, if the heat applied be sufficiently gentle.   But in a strong heat iodine sublimes while the sulphur and antimony combine with oxygen.   This compound is also decomposed by chlorine.   It is not altered by exposure to the direct rays of the sun.   Its taste is sharp and disagreeable, and its smell repulsive.   Water decomposes it, hydriodic acid being formed, and oxide of antimony and sulphur separated. Alcohol and ether deprive it of its iodine, while a yellow powder is deposited.   Sulphurous acid and sulphuretted hydrogen

* Ann. de Chim. et de Phys. xxix. 250.

gas have no action on it. Its constituents, according to the
analyses of Henry and Garot, are

Iodine	.	.	67·9
Sulphur	.	.	8·9
Antimony	.	.	23·2
			100·0*

Now this is very nearly in the proportion of

$1\frac{1}{2}$ atom iodine	.	.	23·625
$1\frac{1}{2}$ atom sulphur	.	.	3
1 atom antimony	.	.	8
			34·625

It is therefore the sesquisulphide of antimony united to an
atom and a half of iodine.

Seleniet.

X. Selenium and antimony combine readily with the pro-
duction of heat and light. The compound melts and forms a
metallic button which has a crystalline texture. When strongly
heated in the air it becomes covered with a vitreous scoria.†

This seleniet combines with oxide of antimony and forms a
yellowish brown transparent mass, very similar in appearance
to glass of antimony.‡

Arseniet.

XI. Antimony forms with arsenic an alloy which is very
brittle, very hard, and very fusible; and composed, according
to Bergman, of 7 parts of antimony and 1 part of arsenic.
Gehlen found that when 15 parts of antimony in powder, and
20 parts of arsenic in powder, are fused together, a button
remains weighing 16·1 parts. It is foliated, very brittle, and
whiter than antimony. If we consider the whole loss as arsenic
the alloy will be a compound of about

8 atoms antimony	.	.	64
1 atom arsenic	.	.	4·75

It is obvious from this that the affinity between arsenic and
antimony is feeble. Neither of them is capable of decompos-
ing the sulphide of the other.

SECTION XII.—OF CHROMIUM.

History.

In the year 1766, Lehman, in a letter to Buffon, published
the first description of a beautiful red mineral with a shade of
yellow, crystallized in four-sided prisms, which is found in the
mine of Beresof, near Ekaterinebourg, in Siberia. This

* Annals of Philosophy (2d series), ix. 152.
† Berzelius, Ann. de Chim. et de Phys. x. 249.   ‡ Berzelius, Ibid.

mineral, known by the name of *red lead ore of Siberia*, was used as a paint, and is now become exceedingly scarce and dear.   It was examined soon after by Pallas, who considered it as a compound of lead, arsenic, and sulphur.   Macquart, who in 1783 was sent upon a mineralogical expedition to the north of Europe, having brought a quantity of it to Paris, analyzed it in 1789, in company with Mr. Vauquelin.   These gentlemen concluded, from their analysis, that it is a compound of the oxides of lead and iron.   On the other hand, Mr. Bindheim of Moscow concluded, from an analysis of his own, that its ingredients are lead, molybdic acid, and nickel.   These discordant analyses destroyed each other, and prevented mineralogists from putting any confidence in either.   This induced Vauquelin, who had now made himself a consummate master of the art of analyzing minerals, to examine it again in 1797.* He found it a combination of the oxide of lead and an acid, with a metallic basis, never before examined.   By exposing this acid to a violent heat along with charcoal powder, he reduced it to the metallic state ; and to the metal thus obtained he gave the name of *chromium*.†   The experiments of Vauquelin have been since repeated and verified by Klaproth,‡ Gmelin,§ and Moussin Pouschkin.‖   Richter has succeeded in reducing chromium to the metallic state, and in ascertaining some of its most important properties.¶   Vauquelin afterwards published a second paper on chromium, in which he examined the properties of chromic acid, and described several of its combinations.**   And Berzelius made a set of experiments to determine the composition of the oxides of this metal,†† which he again repeated and corrected in 1821.‡‡   In the Philosophical Transactions for 1827, I published a paper on some of the combinations of this metal.

How obtained.   Chromium may be obtained from the *bichromate of potash*,

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* Ann. de Chim. xxv. 21, and 194.

† From χρωμα, because it possesses the property of giving colour to other bodies in a remarkable degree.

‡ Crell's Annals, 1798, i. 80.   Mr. Klaproth had examined the *red lead ore* in consequence of the analysis of Bindheim.   His experiments led him to conclude, that the metallic acid, combined with the lead, was not the molybdic, but the acid of some new unknown metal ; but his specimen was too small to enable him to decide the point.   In the mean time, Vauquelin's experiments were published.

§ Ibid. 1799, i. 275.   ‖ Ibid. 1798, i. 355, &c.
¶ Gehlen's Jour. v. 351.   ** Ann. de Chim. lxx. 70.
†† Annals of Philosophy, iii. 101.   ‡‡ Ann. de Chim. et de Phys. xvii. 7.

a beautiful red salt prepared abundantly for the calico printers, and therefore easily procured at a cheap rate. If we add oxalic acid to a solution of this salt in water, and digest it on the sand bath, an effervescence takes place, and it assumes a fine green colour, the chromic acid which it contains, being converted into oxide of chromium. Ammonia being now added to this solution a green matter is separated. This green matter is to be washed and dried, and exposed to a violent heat in a charcoal crucible. By this means it is reduced to the metallic state.

I. Chromium has a white colour intermediate between that Properties. of tin and steel. Its specific gravity according to Richter is 5·9. I found it only 5·093. But I am not certain that my specimen was quite free from cavities.

It is very brittle and easily reduced to powder. Ritter affirms that it is attracted by the magnet. But I did not find this to be the case. Even when in fine powder it would not adhere to a strong magnet.

The heat necessary to fuse it is so high that it never has been obtained except in grains. It conducts electricity. I could neither dissolve it in nitric acid nor in aqua regia, after long continued boiling; but fluoric acid dissolves it readily. It may be exposed to heat, or kept under water, without undergoing much change. When heated with potash, or soda, or the carbonates, or nitrates of these alkalies, it is easily converted into chromic acid.

I found that 3·966 grains of it, when thus treated, became 6·5 grains of chromic acid. Now it will appear afterwards, that 6·5 represents the atomic weight of chromic acid. I conclude, from this experiment, that the atomic weight of chromium is 4.

II. Chromium combines with two proportions of oxygen, Oxides. and forms two compounds, which have been called *green oxide* and *chromic acid*. What has been called *brown* oxide, is merely a compound of chromic acid and green oxide in proportions, which probably vary according to the mode of preparing it.

1. Green oxide of chromium may be obtained by digesting Green oxide. a solution of chromate of potash and oxalic acid, until it assumes a deep green colour, and then adding ammonia to the liquid. It may be obtained also by passing a current of sulphuretted hydrogen gas through a solution of chromate of potash; but in that case its colour is brown. Frick states that it may be ob-

tained for the use of the arts, by dissolving in water the alkaline mass obtained by calcining *chrome iron ore* with nitre, and after filtering the solution, boiling it with sulphur.

Green oxide of chromium, as at first obtained, is in the state of a hydrate. If after washing it sufficiently, we dry it in the open air without the application of heat, it is a light coloured greenish blue powder, tasteless, very light, and easily soluble in acids. If we dry it on a filter, by artificial heat, its colour becomes much darker, and it retains very nearly half its weight of water. The greenish blue matter dried without heat, contains $\frac{13}{15}$ths of its weight of water. A moderate heat expels the water, and leaves the oxide in the state of a very beautiful green powder. When heated nearly to redness, it suddenly *glows*, or becomes red hot, like burning tinder. After this glowing, which does not alter its weight, it loses the property of dissolving in acids. However, a solution may be accomplished by digesting it for a long time in concentrated sulphuric acid.

Atomic weight.

I have shewn, in the Philosophical Transactions for 1827, that the atomic weight of this oxide is 5, and that it is a compound of

1 atom chromium	.	.	4
1 atom oxygen	.	.	1

5

It possesses the characters of an alkaline base, dissolves in acids, and saturates them. The salts which it forms have a green, or blue, or purple colour, and an exceedingly sweet taste.

Brown oxide.

2. What is called *brown oxide* of chromium, is easily obtained by passing a current of sulphurous acid gas through a solution of chromate, or bichromate of potash. The brown matter falls down, and may be washed and dried. It has a flea brown colour, is destitute of taste, and undergoes no alteration when exposed to the air. It is not quite insoluble in water; for after having been agitated with new portions of water above fifty times in succession, the water, which was several hundred times its weight, being left in contact with it for 24 hours, it still continued to give out a little chromic acid to that liquid. When washed with a solution of caustic ammonia, it speedily assumes the usual colour of green oxide. It dissolves in acids with the same phenomena as green oxide, and the solution consists of the usual salt of chromium. The specimens of this brown matter, which I examined, were composed of

6 atoms green oxide of chromium,

1 atom chromic acid.

But probably the proportion of chromic acid will be found to vary in different circumstances. It is obvious from all this, that *brown oxide of chromium* ought not to be considered as a peculiar oxide, but rather as a combination of green oxide and chromic acid, or more probably, a mixture of green oxide and chromate of chromium.

Green oxide of chromium is used as a green paint for porcelain vessels. The colour is remarkably fine, and it is easily applied. According to Vauquelin, the green colour of the emerald is owing to the presence of a little green oxide of chromium in the mineral.

3. A method of preparing chromic acid, in a state of purity, Chromic acid. was first discovered by M. Unverdorben. It is as follows: Mix together 4 parts of chromate of lead, 3 parts of pure fluor spar (previously heated to redness and pounded), and 5 parts of sulphuric acid as concentrated as possible. This mixture How prepared. must be put into a leaden or platinum retort, and a gentle heat applied by means of a lamp. A red gas is formed, which appears in the air, under the form of red or yellow vapours. This gas, when placed in contact with water, is absorbed and converted into fluoric and chromic acids. By evaporating the solution in a platinum capsule, the fluoric acid is driven off, and pure chromic acid remains.

Berzelius found that if the gas was made to pass into a platinum vessel, containing a little water at its bottom, and whose mouth is covered with moist paper, the gas is decomposed in the moist air within the dish, and abundance of small cinnabar red crystals of chromic acid are deposited, which gradually fill the whole dish. These crystals are very bulky, and sink down on the least pressure. When the gas is disengaged very slowly, these crystals become larger and more solid; but they are never regular. They consist of pure chromic acid. However, chromic acid may be obtained in regular four-sided prisms, with square or rectangular bases, by a very cautious evaporation of its solution in water; and for that purpose acid must be employed quite free from all admixture of green oxide of chronium.

Maus has given another process for preparing chromic acid, which deserves attention on account of its facility. It is as follows: Dissolve bichromate of potash in water, and pass a current of fluosilicic acid through the solution. By this means

the potash is thrown down in combination with fluosilicic acid. Decant off the clear liquid, and evaporate it to dryness by a very gentle heat, in a platinum capsule. Dissolve the dry acid in a little water, and a little fluosilicate of potash will remain. The chromic acid thus obtained must not be filtered, otherwise a portion of it will be converted into green oxide. This rule indeed should be always attended to. Whenever chromic acid is passed through paper, it becomes contaminated with green oxide.

Properties. Chromic acid when evaporated to dryness is almost black while hot, and of a deep red when cold. It has no smell; and its taste is intensely sour, leaving a styptic impression behind. It stains the skin yellow, and the stain cannot be removed by washing with water, but may by an alkali. It absorbs moisture from the atmosphere, and is converted into a dark brown viscid liquid. By very cautious concentration it may be obtained in red crystals, which appear to the eye to be four-sided right prisms, with square bases. When the crystals obtained from fluoride of chromium are suddenly heated on platinum foil they melt, and are decomposed with a bright light, oxygen gas being disengaged, and green oxide remaining. I could not succeed in producing complete decomposition of this acid in the highest temperature that green glass could bear without fusion. The crystals containing water do not exhibit the phenomenon of *glowing.* Chromic acid is soluble in alcohol. The solution is partially decomposed by heat, ether being evolved and green oxide of chromium precipitated. The solution has now a yellow colour, and contains a good deal of chromic acid undecomposed.

Sulpho-chromic acid. The original method of obtaining chromic acid proposed by Vauquelin, was to dissolve *chromate of barytes* in nitric acid, and then to add enough of sulphuric acid to throw down all the barytes, taking care not to add any excess. The liquid freed from sulphate of barytes is to be evaporated to dryness to drive off the nitric acid. Being re-dissolved and cautiously concentrated, it yields crystals in small ruby coloured prisms. These crystals were long taken for pure chromic acid. Gay-Lussac* first shewed that they consist of a compound of sulphuric and chromic acid. They have a very acid, acrid, and metallic taste. When heated, this acid is decomposed more easily than pure chromic acid, being converted into sulphate of chromium. Hence it is evident that it is a compound of

* Ann. de Chim. et de Phys. xvi. 102.

1 atom sulphuric acid	.	.	5
1 atom chromic acid	.	.	6·5
			———
			11·5

Many substances occasion a similar decomposition. When heated with muriatic acid chlorine is given out, and the same change produced.

A mixture of chromic acid, and muriatic acid, has the property of dissolving gold.

A very careful analysis of chromate of potash gave me the following result:

Chromic acid	.	.	6·5
Potash	.	.	6

While I found bichromate composed of

Chromic acid	.	.	13
Potash	.	.	6

From this it is obvious that the atomic weight of this acid is 6·5. Farther I shewed that 13·5 grains of protoxide of iron, dissolved in sulphuric acid, and mixed with 6·5 grains of chromic acid, reduce the chromic acid to 5 grains of green oxide of chromium, while the iron is peroxydized. Now to peroxydize 13·5 grains of protoxide of iron, it is necessary to add 1·5 atoms of oxygen. From this it is clear that chromic acid is a compound of

Green oxide	. .	.	5
Oxygen	.	.	1·5
			———
			6·5

Atomic weight.

But green oxide contains 1 atom of oxygen united to 4 chromium. Consequently chromic acid is a compound of

1 atom chromium	.	.	4
$2\frac{1}{2}$ atoms oxygen	.	.	2·5
			———
			6·5

So that the constitution of this acid is the same as that of phosphoric acid, arsenic acid, and antimonic acid, and also hyposulphuric acid.

III. Chlorine and chromium probably unite in various proportions. But the subject has hitherto been but imperfectly investigated.

Chlorides.

1. Muriatic acid readily dissolves the green oxide of chromium; the solution has a deep green colour and a sweet taste, and always contains a great excess of acid. When evaporated

to dryness, and kept for some time in that state, it assumes the form of red coloured scales.   These scales are probably a simple chloride of chromium composed of an atom of each constituent, though I did not succeed in driving off all excess of acid.   They dissolve readily in water, forming a deep green solution, having a sweet and acidulous taste.   If we raise the heat sufficiently high to drive off all excess of acid we obtain the chloride in the form of green scales; quite tasteless and insoluble in water and acids.

2. There is another compound of this substance with chlorine which I discovered in 1824, and to which I gave the name of *chlorochromic acid.**   It may be obtained by the following process.

Triturate together in a mortar 190 grains of dry bichromate of potash, and 225 grains of decrepitated common salt.   Put this mixture into a tubulated retort, and pour into it 500 grains of concentrated sulphuric acid, and by agitation make it up into a magma with the salts.   Then apply the flame of a lamp to the bottom of the retort.   An effervescence takes place and beautiful red fumes soon make their appearance.   These condense in the beak of the retort and gradually drop into the receiver under the form of a red coloured liquid.   The process lasts about ten minutes or a quarter of an hour, when the evolution of the red fumes suddenly stops.   The matter in the retort has now assumed a green colour.   The distillation must now be stopped.   Should it be continued an acidulous water passes into the receiver and destroys the red liquid.   The quantity of red liquid obtained from the above mentioned quantity of materials is about 200 grains.   The produce is greatest when the atoms of chlorine in the salt are to those of chromic acid as 3 to 2.   The liquid thus obtained has the following properties.

The colour is a fine, but very deep crimson; the taste sweetish, astringent, and acid.   The smell of chlorine is fully as intense as that of chlorine gas itself.   It reddens vegetable blues.   Its specific gravity is 1·9134.   When 151·5 grains of it were poured into an ounce of water at 50° the temperature

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* My account of it was read to the Royal Society in March 1826, but it had been at least six months in the hands of the secretary before it was read.   Mean while a short account of the same substance appeared in Ann. de Chim. et de Phys. in a letter dated 6th May, 1826, by Dumas, who gives some of its properties, and says that it had been discovered by Unverdorben.

rose at once to 212°, and chlorine gas was given out so abundantly as to occasion an effervescence.

When dropt into water it falls to the bottom and exhibits the appearance of a drop of oil. Globules of chlorine gas are given out rather abundantly till the drop disappears, rendering the water yellow. The liquid now contains chlorine, chromic acid, and a trace of green oxide of chromium. When it is dropt into oil of turpentine or alcohol it sets these conbustible substances on fire, and they burn quietly with a flame having a good deal of blue mixed with white. When dropt upon flowers of sulphur they take fire and burn with a fine red flame. It acts violently on olive oil, and pyroxylic spirit, and naphtha, but sets none of them on fire. It has no action on dry phosphorus even when fused in it; but if the phosphorus be moist, or if the least water be present, the phosphorus burns violently or even explodes.* It acts very feebly upon metals. Zinc and tin filings effervesce slightly. On iron it does not act till heated: on copper and antimony it does not act at all. With mercury it forms a mass of the consistence of hog's lard, but the metal retains its colour and lustre. It sets fire to ammoniacal gas.

From a set of experiments which I made to determine its Composition. constituents, it follows that it is a compound of 1 atom chlorine (4·5) and one integrant particle of chromic acid (6·5) united together and condensed into a liquid. Its atomic weight is 11, and it possesses the characters of an acid as far as reddening vegetable blues is concerned. I did not succeed in the attempts that I made to unite it to bases.

Dumas considers it as a compound of 1 atom of chromium with three atoms of chlorine. But I am ignorant of the way in which he deduced these constituents. If it were a chloride analogy would lead us to view it as a compound of

$$2\tfrac{1}{2} \text{ atoms chlorine} \qquad . \qquad . \qquad 11{\cdot}25$$
$$1 \text{ atom chromium} \qquad . \qquad . \qquad 4$$

And this was the view of its composition which I was myself disposed to take at first. But it is not easy to see any force which could deprive the chromic acid of its oxygen. Nothing else is present but chlorine, and chlorine has not so great an

* I received soon after the publication of my paper in the Phil. Trans., a letter from Dr. Torrey of New York, mentioning, that when he was exhibiting it to his class, it detonated violently with phosphorus. The receipt of this letter led me to investigate the subject carefully. The result is what I have stated in the text.

affinity for oxygen as chromium has. My analysis does not decide the state of the constituents in this compound, but only their proportions. It contains only 1 atom of chlorine to 1 atom of chromium. The chlorine is undoubtedly much more loosely united than in the protochloride. I think therefore that it is much more likely to be in the state of chlorochromic acid than that of chloride of chromium.

IV. We are unacquainted at present with the bromides and iodides of chromium.

Fluoride.

V. When fluor spar, chromate of lead, and concentrated sulphuric acid, in the proportions indicated in page 335, are heated in a leaden or platinum retort, a red coloured gas is formed which is immediately decomposed when it comes in contact with glass. This gas, first observed by M. Unverdorben, is considered as a *fluoride of chromium*, though no very satisfactory proofs that this is its composition have been adduced. From the corrosive action of this gas on glass it has been hitherto impossible to investigate its properties. It is permanent at the usual temperature of the atmosphere. When mixed with ammoniacal gas it burns with explosion. It gradually corrodes and dissolves resin. It is absorbed by water forming a yellow coloured liquid, which, when evaporated, leaves pure chromic acid.* A fuller examination of this gas would be particularly interesting.

VI. We are still unacquainted with the compounds which chromium may be capable of forming with hydrogen, azote, carbon, boron, and silicon.

Phosphuret.

VII. When phosphorus is made to pass through green oxide of chromium heated to redness in a green glass tube, a brilliant combustion takes place, and phosphuret of chromium is formed. This phosphuret, when formed, by passing 3·2 parts of phosphorus through 5·08 parts of anhydrous green oxide of chromium, has a brown colour, is tasteless, and insoluble in water and acids. It still continues in the state of a loose powder which is agglutinated together, but not melted by the action of the blow-pipe. Its constituents are

1 atom phosphorus   .   .   2
1 atom chromium   .   .   4
                                   ——
                                    6

Hence its atomic weight is 6.

* Gmelin's Handbuch der Chemie, i. 855.

VIII. Sulphuret of chromium may be obtained by various processes. H. Rose obtained it by passing a current of dry sulphuretted hydrogen gas over green oxide of chromium heated to redness in a porcelain tube. M. Lassaigne obtained it by mixing together equal weights of dry chloride of chromium and flowers of sulphur, and heating it gradually in a bent glass tube, raising the temperature as high as the glass will bear. There is disengaged first a little sulphuretted hydrogen, then muriatic acid, then sulphur, and lastly dense vapours of chloride of sulphur.

The sulphuret of chromium thus formed is blackish gray, unctuous to the touch, and friable. It stains bodies like plumbago when rubbed over them. When heated in the open air it burns like pyrophorus leaving green oxide of chromium. It dissolves in nitric acid, and still more readily in aqua regia. Its composition, according to Lassaigne, is

Chromium	. .	20
Sulphur	. .	2·108

This is equivalent to 1 atom sulphur and $4\frac{1}{2}$ atoms chromium.[*] But as sulphuret of chromium by digestion in nitric acid may be converted into sulphate of chromium, it is clear that its true constituents are

1 atom sulphur	. .	2
1 atom chromium	. .	4
		——
		6

And that its atomic weight is 6.

IX. Nothing is known respecting the compounds which chromium may form with selenium, tellurium, arsenic, and antimony.

The chromates possess poisonous qualities when taken internally. The hands of many persons when dipt into a solution of bichromate of potash break out into malignant ulcers.

SECTION XIII.—OF URANIUM.

There is a mineral found in the George Wagsfort mine at Johan-Georganstadt, in Saxony, partly in a pure or unmixed state, and partly stratified with other kinds of stones and earths. The first variety is of a blackish colour, inclining to a dark iron gray, of a moderate splendour, a close texture, and when broken presents a somewhat even, and (in the smallest particles)

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[*] Ann. de Chim. et de Phys. xiv. 299.

a conchoidal surface.   It is quite opáque, tolerably hard, and on being pounded yields a black powder.   Its specific gravity is about 7·500.   The second sort is distinguished by a finer black colour, with here and there a reddish cast : by a stronger lustre not unlike that of pitcoal; by an inferior hardness; and by a shade of green, which tinges its black colour when it is reduced to powder.*

This mineral was called *pechblende;* and mineralogists, misled by the name,† had taken it for an ore of zinc, till Werner, convinced from its texture, hardness, and specific gravity, that it was not a *blende*, placed it among the ores of iron.   After-wards he suspected that it contained *tungsten;* and this con-jecture was seemingly confirmed by the experiments of some German mineralogists, published in the Miners' Journal.   But Klaproth examined this ore in 1789, and found that it consists chiefly of sulphur, combined with a peculiar metal, to which he gave the name of *uranium.*‡

Uranium was afterwards examined by Richter, and an elabo-rate set of experiments has been published on it by Bucholz.§ In the year 1822 an elaborate set of experiments on the oxides of uranium was made by M. Arfvedson;‖ which were carried still farther by Berzelius in 1823.¶   And I made some expe-riments on the subject which were published in 1825.**

The only ore from which uranium can be obtained in suf-ficient quantity for investigation is *pitchblende*, which occurs in various mines in Saxony and Bohemia, and has been found also in Cornwall.   This ore consists of a great variety of sub-stances mechanically mixed together, and which can only be separated by mechanical processes.   Three methods of obtain-ing pure oxide of uranium from this ore have been proposed by chemists, which it may be worth while to specify.

Method of procuring it.   1. Arfvedson's method was this.   Finely pulverised pitch-blende was dissolved by a gentle heat in a mixture of nitric and muriatic acids.   After the decomposition of the mineral was completed, and most of the acid expelled, a little muriatic

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* Klaproth, Crell's Jour. Eng. Trans. i. 126.

† *Blende* is the name given to ores of zinc.

‡ From *Uranus* (Ουρανος) the name given by Mr. Bode to the new planet discovered by Herschel; which name the German astronomers have adopted. Mr. Klaproth called the metal at first *uranite;* but he afterwards changed that name for *uranium.* '

§ Gehlen's Jour. iv. 17.

‖ Kong. Vet. Acad. Hand. 1822, p. 404.   ¶ Ibid. 1823, p. 152.

** First Principles, ii. 18.

acid was added, and then the liquid was diluted with a good deal of water. The sulphur, silica, and stony matter remained undissolved. A current of sulphuretted hydrogen gas was now passed through the liquid as long as any precipitate fell. By this process the lead and copper are thrown down, and likewise the arsenic, should the liquid contain any, To the filtered liquid a little nitric acid was added, and the whole was digested to peroxidize the iron. By this process the liquid changed from light green to yellow. Carbonate of ammonia was now added in excess. The peroxide of iron was thrown down, but the peroxide of uranium was held in solution, together with oxides of cobalt and zinc when they happen to be present. The filtered solution was then made to boil, and the boiling continued as long as carbonate of ammonia was disengaged. A portion of the oxide of cobalt remained in solution; but another portion was precipitated along with the peroxide of uranium, as was also the oxide of zinc. The precipitate was collected on a filter, washed, and dried. It was then exposed to a red heat, which deprived it of its yellow colour and made it dark green. It was now macerated in dilute muriatic acid, which dissolved the oxides of cobalt and zinc, together with a small portion of the oxide of uranium. Pure protoxide of uranium remained behind in the state of a green powder.*

2. The process of M. Berthier is as follows. He reduced it to powder and boiled it with muriatic acid for some time. It was then thrown on a filter and well washed. The matter thus collected on the filter (which is pitchblende freed from several impurities), was treated with nitric acid till it lost its black colour and was completely decomposed. The solution was evaporated to dryness by a gentle heat, agitating it frequently. It was then boiled in water and the solution filtered. The undissolved portion consisted of alumina, silica, sulphate of lead, oxide of iron, and arseniate of iron, together with a small quantity of oxide of uranium which was neglected. The solution contained almost all the oxide of uranium, together with some lead, copper, iron, and occasionally alumina and lime. A little sulphate of ammonia was dropt into it, which threw down the lead. Then a current of sulphuretted hydrogen gas was passed through it, which threw down the copper and the arsenic when the liquid happened to contain any, and the iron was reduced to the state of protoxide. The liquid was then left for some time to itself to allow the sulphuretted hydrogen gas

* Annals of Philosophy (2d series), vii. 254.

to be dissipated. When no traces of sulphuretted hydrogen remained, carbonate of ammonia was added cautiously by a little at a time, and with continual agitation, and in such quantity as only to throw down the peroxide of uranium. The precipitate was allowed to deposite itself in a well corked phial to prevent the peroxidizement of the iron. The liquid portion was then drawn off, and the phial filled with distilled water recently boiled, which was drawn off in its turn, and the peroxide of uranium finally collected on a filter and washed.*

3. The process which I employed for procuring pure protoxide of uranium, was still simpler and easier than either of the preceding. The pitchblende reduced to a fine powder, was digested in nitric acid, till every thing soluble was taken up. The solution was then rendered as neutral as possible by evaporation, and a current of sulphuretted hydrogen gas passed through it as long as any precipitate continued to fall. The liquid was filtered and heated to drive off all traces of sulphuretted hydrogen. It was now precipitated by caustic ammonia, and the precipitate, after being well washed, was digested, while still moist, in a pretty strong solution of carbonate of ammonia. A fine lemon yellow liquid was obtained, which being set aside for a few days, deposited abundance of fine yellow crystals in four-sided right prisms with rectangular bases. These crystals being exposed to a red heat, gave out water and carbonate of ammonia and oxygen gas, and left protoxide of uranium in the state of a black powder, having a good deal of lustre; but which, when reduced to powder, had a dark green colour.†

I found the yellow crystals a compound of

3 atoms carbonate of ammonia	. .	14·625
1 atom percarbonate of uranium	. .	30·75
4 atoms water	.	4·50

$$\overline{}$$

49·875

II. Protoxide of uranium is easily reduced to the metallic state, by passing a current of dry hydrogen gas over it, placed in a glass tube, and heated by a spirit lamp, as was first practised by Arfvedson. Water is formed, and the uranium in the act of reduction becomes red hot. The uranium, when reduced in this way, assumes a liver brown colour, and still continues in powder. Bucholz and Richter reduced

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* Ann. de Mines, x. 141.   † First Principles, ii. 3.

it to the metallic state, by mixing it with a little charcoal powder, and then exposing the mixture to a violent heat in a blast furnace. It can only be obtained in small grains: no heat that we can raise, being sufficient to melt it into a mass.

Its colour, when thus obtained, is iron gray; it has considerable lustre, and is soft enough to yield to the file. Its malleability and ductility are of course unknown. Its specific gravity, in Klaproth's trials, was only 8.100. But Bucholz obtained it as high as 9·000. Properties.

Uranium reduced by hydrogen gas undergoes no change in the ordinary temperature of the atmosphere; but when heated to redness, it takes fire, swells, and is converted into green oxide. It is insoluble in sulphuric and muriatic acids, whether concentrated or diluted; but nitric acid dissolves it with facility, deutoxide of azote being given out, and the solution has a lemon yellow colour.

III. Uranium combines with two different proportions of oxygen, and forms two oxides. The protoxide is green, and the peroxide or acid of uranium is yellow. Oxides.

1. The green oxide is obtained by the processes already described, or by exposing metallic uranium to a red heat. Its colour, while in grains, is black: but when in powder, it is dark green. It is soluble in sulphuric and muriatic acid; but the solution goes on very slowly, except when the oxide is in the state of a hydrate, and we can obtain it in that state by precipitating it from an acid solution. In that state, it is in purple coloured flocks, and it cannot be dried without being at least partially oxidized. The solutions of this oxide in acids are green. When the protoxide of uranium is dissolved in nitric acid, it is converted into peroxide. Protoxide of uranium is tasteless, and when anhydrous, it is not altered by exposure to the air. None of the salts which it forms with acids, so far as I have tried them, are capable of crystallizing. Protoxide.

Various experiments have been made to determine the composition of protoxide of uranium. Bucholz found that 100 parts of metallic uranium, when converted into protoxide by heat, became 105·17 parts.* Arfvedson repeated the same experiment, and the mean of two trials was, that 100 uranium, when converted into protoxide, became 103·7113. By reversing the experiment, or by reducing the protoxide of

* Gehlen's Jour. iv. 35.

uranium to the metallic state, by means of a current of hydrogen gas, he found it composed of 100 uranium, and 3·67 oxygen. The mean of these two sets of experiments by Arfvedson, give the constituents of protoxide of uranium as follows:

$$\text{Uranium} \quad . \quad . \quad 100$$
$$\text{Oxygen} \quad . \quad . \quad 3 \cdot 69$$

and with this result, the trials of Berzelius almost exactly agree. Now, the probability is, that this oxide is a compound of 1 atom uranium, and 1 atom oxygen. If this be the case, we will obtain the atomic weight of uranium, by dividing 100 by 3·69. And $\dfrac{100}{3 \cdot 69} = 27 \cdot 1 =$ atomic weight of uranium.

But I consider myself entitled from my analysis of the ammonio-carbonate of uranium, to consider the true atomic weight of this metal to be 26.* On that supposition, the protoxide of uranium will be a compound of

Composition.
$$1 \text{ atom uranium} \quad . \quad . \quad 26$$
$$1 \text{ atom oxygen} \quad . \quad . \quad 1$$
$$\overline{\quad 27 \quad}$$

And its atomic weight will be 27.

Peroxide. 2. Peroxide of uranium, or uranic acid, as it might be called, is easily obtained by dissolving protoxide of uranium in nitric acid, and precipitating by caustic ammonia. A beautiful yellow powder is obtained, which is a combination of peroxide of uranium and ammonia. Such is its tendency to combine with other bodies, that it cannot be obtained in a separate state. If we attempt to drive off the ammonia and water with which it is united, it loses oxygen at the same time, and is converted into protoxide. The same change takes place when we heat pernitrate of uranium. It possesses the property, as Arfvedson has shown, of uniting both with acids and bases, and forming salts with each; so that it has the double property of acting at once as an acid and a base. In this respect, it agrees with several other weak acids, which will be described in the subsequent sections of this chapter.

Arfvedson made an elaborate set of experiments to determine the composition of this oxide. He formed uraniate of lead, and found by analysis that it was a compound of

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* First Principles, ii. 4.

Uranic acid . . 99·12 or 10·6
Protoxide of lead . . 130·88 or 14
                                    ——————
                                    230·00

He reduced the constituents of this salt to the metallic state, by passing a current of hydrogen gas over 230 parts of it. The water evolved was 16·4 parts, containing 14·577 parts of oxygen. Now 130·88 parts of protoxide of lead, contain 9·35 parts of oxygen. Consequently the 99·12 parts of peroxide of uranium contained 5·22 parts of oxygen. Hence peroxide of uranium must be a compound of

Uranium . . 100
Oxygen . . 5.559

Another experiment gave the oxygen united to 100 uranium in the peroxide 5·5765. The mean of these two is

Uranium . . 100
Oxygen . . 5·56775

Now he had determined by experiments stated above, that protoxide of uranium is a compound of 100 uranium + 3·69 oxygen. So that the oxygen in the two oxides, united to the same weight of uranium, have the ratio of 3·69 to 5·56775, numbers almost exactly in the ratio of 2 to 3, or of 1 to $1\frac{1}{2}$. Hence the peroxide of uranium ought to be a compound of

1 atom uranium . . 26
$1\frac{1}{2}$ atom oxygen . . 1·5
                             ——————
                             27·5

But in some of his other experiments, as for example his analysis of uraniate of barytes, he found the quantity of oxygen still greater than what I have just stated. 1·343 parts of uraniate of barytes were found composed of

Barytes . . . . 0·1933 or 9·5
Peroxide of uranium . . 1·1497 or 56·5
                                ——————
                                1·3430

The peroxide of uranium being converted into protoxide, was reduced to 1·121 parts. According to this experiment, peroxide of uranium is composed of 1·121 parts of protoxide, and 0·0287 parts of oxygen, or of 100 parts of protoxide, and 2·56 parts of oxygen. But 100 protoxide contain 3·7 oxygen. Consequently by this experiment, peroxide of uranium is composed of

Uranium . . 100
Oxygen . . 6·5

Now, 3·69 is to 6·5, as 1 to 1·76, which approaches more nearly the ratio of 1 to 2, than that of 2 to 3.

The atomic weight of barytes, is 9·5; and uranate of barytes was found by Arfvedson, to be a compound of

Barytes . . . . 9·5
Peroxide of uranium . . 56·5

Now if the salt be a compound of 1 atom barytes, and 2 atoms uranic acid, then the atomic weight of uranic acid will be 28·25.

Composition.

I analyzed the potash persesquisulphate of uranium, and the persesquinitrate of uranium, and obtained in each 28 for the atomic weight of uranium.* These circumstances induce me rather to consider the oxygen in the peroxide as double that in the protoxide. If this supposition (which in the present state of our knowledge is by far the most probable) be admitted, then the composition of the two oxides of uranium will be as follows:

	Uranium.	Oxygen.		Atomic weight.
1. Protoxide	1 atom	+ 1 atom	. .	27
2. Peroxide	1	+ 2	. .	28

III. No experiments have been made upon the compounds which uranium is capable of forming with chlorine, bromine, and iodine. This is to be regretted, because the accurate knowledge of the proportions in which these bodies unite with it, would decide whether the ratio of combination be 1 and $1\frac{1}{2}$, or 1 and 2. The analyses of the chlorides and bromides, and iodides, would be easier and much more certain, in consequence of the high atomic weight of the chlorine, bromine, and iodine.

IV. Nothing is known respecting the combinations which uranium may be capable of forming with hydrogen, azote, carbon, boron, silicon, and phosphorus.

Sulphuret.

V. The sulphurets of uranium have been very imperfectly investigated. Klaproth mixed the peroxide of uranium with twice its weight of sulphur, and heated it in a retort till most of the sulphur was driven off. The residuum was a blackish brown compact mass. By increasing the heat, the whole of the sulphur was driven off, and the uranium remained in the metallic state, in the form of a black heavy coarse powder.† Bucholz's experiments, though made in a different way, led nearly to the same result. He boiled a mixture of sulphur and oxide of uranium in an alkaline solution to dryness, heated the residue to redness, and then treated it with distilled water. A black-

* First Principles, ii. 18.   † Beitrage, ii. 213.

ish brown powder remained behind, and small needles of a red colour appeared in the solution. In one trial, the compound which he obtained gave out some sulphuretted hydrogen when dissolved in muriatic acid. This is a proof that it was not a sulphuretted oxide, but a sulphuret of uranium.*

M. H. Rose succeeded in forming a sulphuret of uranium, by passing very slowly a current of bisulphuretted carbon vapour over protoxide of uranium, heated to redness in a porcelain tube. The sulphuret thus formed is black, and when rubbed assumes the metallic lustre. When heated in an open vessel the sulphur burns, and protoxide of uranium remains behind. Muriatic acid scarcely acts upon it; but nitric acid readily dissolves it even without exposure to it, and the sulphur remains.

When a hydrosulphuret of an alkali is poured into a neutral solution of protoxide, or peroxide of uranium in an acid, a black precipitate falls, which has not been examined. But it probably consists of two distinct sulphurets (according to the oxide acted on) analogous to the oxides.

VI. Nothing is known respecting the combinations which uranium may be capable of forming with selenium, tellurium, arsenic, antimony, or chromium; the scarcity of this metal having hitherto put it out of the power of chemists to make the requisite experiments on the subject.

SECTION XIV.—OF MOLYBDENUM.

1. The Greek word μολυβδαινα, and its Latin translation History. *plumbago*, seem to have been employed by the ancients to denote various oxides of lead; but by the moderns they were applied indiscriminately to all substances possessed of the following properties: light, friable, and soft, of a dark colour and greasy feel, and which leave a stain upon the fingers. Scheele first examined these minerals with attention. He found that two very different substances had been confounded together. To one of these, which is composed of carbon and iron, and which has been already described, he appropriated the word *plumbago;* the other he called *molybdena.*

Molybdena is composed of scaly particles adhering slightly to each other. Its colour is bluish, very much resembling that of lead. Scheele analyzed it in 1778, and obtained sulphur and a whitish powder, which possessed the properties of an

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* Gehlen's Jour. iv. 47.

acid, and which, therefore, he called *acid of molybdena*.* Berg-man suspected this acid, from its properties, to be a metallic oxide; and at his request, Hjelm, in 1782, undertook the laborious course of experiments by which he succeeded in obtaining a metal from this acid. His method was to form it into a paste with linseed oil, and then to apply a very strong heat. This process he repeated several times successively.†
To the metal which he obtained he gave the name of *molyb-denum*.‡ The experiments of Scheele were afterwards repeated by Pelletier,§ Ilseman,‖ and Heyer;¶ and not only fully con-firmed, but many new facts were discovered, and the metallic nature of molybdic acid was put beyond a doubt: though, in consequence of the very violent heat necessary to fuse molyb-denum, only very minute grains of it have been hitherto obtained in the state of a metal. In 1795, Mr. Hatchett pub-lished a very valuable set of experiments, which throw much new light upon the nature of this metal.** We are indebted to Bucholz for a very elaborate and important set of experiments on this refractory metal and its compounds.††

In 1825, Berzelius published an elaborate and satisfactory set of experiments on the oxides of molybdenum, and the salts which they form, by combining with acids.‡‡

The simplest method of procuring molybdenum in a state of purity seems to be that put in practice by Hjelm. Molybdena is roasted in a moderate red heat slowly and repeatedly, till the whole is reduced to the state of a fine powder, and passes through a sieve. The powder is to be dissolved in ammonia, the solution filtered, and evaporated to dryness. The residuum being moderately heated (adding a little nitric acid) leaves a white powder, which is the pure oxide of molybdenum.§§ By mixing this oxide with some oil or charcoal powder, and exposing it to a violent heat, it is reduced to the metallic state. The method followed by Bucholz was nearly similar. He has shown that heat reduces the oxide to the metallic state without its being necessary to add any charcoal. But no heat which he could raise was high enough to melt this refractory

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* Scheele, i. 236.   † Bergman's Sciagraphia, p. 19, Eng. trans.
‡ Crell's Annals, 1790, i. 39, &c.   § Jour. de Phys. 1785, Decembre.
‖ Crell's Annals, 1787, i. 407.   ¶ Ibid. 1787, ii. 27, and 124.
** Phil. Trans. 1795, p. 323.   †† Gehlen's Jour. iv. 398.
‡‡ Kongl. Vetensk. Acad. Handl. 1825, p. 145.
§§ Crell's Annals, iii. 338, Eng. transl.

metal into a solid button. The experiments of preceding chemists had been equally unfortunate.

The most convenient way of obtaining metallic molybdenum for chemical purposes is to put a quantity of molybdic acid into a porcelain tube, which passes through a furnace, to heat it to whiteness, and then pass a current of dry hydrogen gas through it as long as water continues to be formed. It is then allowed to cool, taking care to keep the porcelain tube filled with hydrogen gas all the time. By this process, molybdenum is obtained in the state of a grayish powder susceptible of polish, and then assuming the metallic lustre.

I. Hitherto the metal has been obtained only in small grains, or in pieces imperfectly agglutinated, and which break readily when struck. Its colour, from the observations of Bucholz, seems to be a silvery white; but it frequently has a shade of yellow. Hjelm found its specific gravity only 7·400; but Bucholz, whose specimens had doubtless been exposed to a more violent heat, and were more compact, found it as high as 8·615 or even 8·636.* Molybdenum is brittle. It is not altered though kept under water. Its affinity for oxygen is not great. Hence it is not liable to undergo alteration when exposed to the atmosphere.

Neither dilute sulphuric acid, nor muriatic acid, nor fluoric acid, dissolve it. But concentrated sulphuric acid attacks it; sulphurous acid is disengaged, and a brown matter formed. Nitric acid dissolves it, and either forms a nitrate of molybdenum or molybdic acid, according to the proportion of the acid employed. It dissolves readily in aqua regia. When heated with nitre it is oxidized with rapidity. Hydrate of potash does not dissolve it by boiling; and when the molybdenum and hydrated potash are heated in a crucible, the action is very slow and imperfect.

II. When the metal is heated to redness in an open vessel, it absorbs oxygen, and is converted into a brown powder, which becomes reddish if the heat be long continued, and at last, according to Bucholz, becomes blue. When the heat to which the metal is exposed is still higher, the molybdenum takes fire, and burns without flame, smokes, and deposites small brilliant white needles, which constitute molybdic acid. So far as we know at present, this metal combines with three different proportions of oxygen, and forms three oxides, the first two of

which possess the characters of salifiable bases; but the last is an acid. My knowledge of the protoxide is entirely derived from the experiments of Berzelius. I did not succeed in the experiments which I tried in satisfying myself of its peculiar nature. But from analogy there can be little doubt of its existence.

Protoxide.
1. The method of obtaining protoxide of molybdenum, employed by Berzelius, was the following: Dissolve a molybdate in a small quantity of water; pour muriatic acid into the liquid till the molybdic acid at first thrown down be again dissolved; then digest the solution with distilled zinc. The liquid becomes first blue, then reddish brown, and at last black. If we continue the action of the zinc long enough, the protoxide of molybdenum falls down in the state of a black hydrate; but in general it remains in solution. To throw it down add as much ammonia as is sufficient to throw down the oxide of molybdenum, without acting upon the zinc in solution. Wash it repeatedly with water, containing caustic ammonia, to dissolve any oxide of zinc which may be mixed with it, then with pure water. Dry it first between folds of filtering paper, and then by placing it in the vacuum of an air-pump, over sulphuric acid. It is very difficult to dry it without the absorption of more oxygen. Berzelius says that the last portions of oxide of zinc may be removed by mixing a molybdate with a greater quantity of muriatic acid than is necessary to saturate its base, and then agitating it with mercury, in which only a little potassium has been dissolved, so as to prevent it from being decomposed too rapidly. The black liquid is now to be precipitated by caustic ammonia. The precipitate, when washed and dried, is pure hydrated protoxide of molybdenum. I have not tried this process; but with the zinc I doubt whether it be possible to obtain an oxide of molybdenum fit for analysis.

If we put a quantity of molybdic acid into muriatic acid, and a piece of zinc along with it, and continue the action for a considerable time, the molybdic acid becomes black without dissolving, and is converted into protoxide of molybdenum. But it cannot be dried without absorbing oxygen, and being converted into deutoxide, or even partly into molybdic acid; for it always assumes a blue colour.

Protoxide of molybdenum dissolves with difficulty in acids. The solution is black and opaque; but when very dilute it has a grayish brown colour. The taste of these solutions is simply astringent. When the hydrated protoxide is heated in

vacuo, it parts with its water slowly. If we raise the heat (after it has become anhydrous) to an incipient red, it glows and scintillates. The protoxide is now under the form of a black powder, and is insoluble in all açids. When the protoxide is heated in the open air it takes fire, burns faintly, and is converted into molybdic acid. This oxide neither dissolves in caustic potash nor in the alkaline carbonates.

The attempts of Berzelius to determine the quantity of oxygen in this oxide were unsuccessful. Supposing the black oxide to exist, there can be little doubt from analogy that it is a compound of

Molybdenum	.	.	6
Oxygen	.	.	1
			—
			7

and that its atomic weight is 7. For it will appear, as we proceed, that the atomic weight of molybdenum is 6. This oxide, then, is a protoxide, and contains 1 atom of oxygen united to 1 atom of the metal.

2. The deutoxide is the oxide which I described in the last Deutoxide. edition of this work, under the name of protoxide. It was discovered by Bucholz, who obtained it by the following process: Put dry molybdate of ammonia into a crucible, cover it with charcoal powder, and expose it to a white heat. The brown oxide will be found at the bottom of the crucible. It has a crystallized appearance, a deep copper colour, and a specific gravity of 5·666.

The most advantageous mode of preparing this oxide, according to Berzelius, is to mix dry molybdate of soda with sal ammoniac, and to heat the mixture rapidly in a covered platinum crucible till it ceases to exhale fumes of sal ammoniac. Let the crucible cool, and wash what it contains with water, which dissolves common salt, and leaves the deutoxide of molybdenum in the state of a very dark brown powder.

Thus prepared it is very dark coloured, but appears purple in the light of the sun. It is insoluble in acids. Concentrated sulphuric acid, indeed, and bitartrate of potash, dissolve a little of it; but how long soever the action be continued, they never take up any more. Nitric acid converts it into molybdic acid. Muriatic and fluoric acid have no action on it; nor is it acted on by an alkaline ley.

But when this oxide is in the state of a hydrate, it dissolves in acids, and is capable of forming salts with them. Now

we may obtain it in this state by the following process: Digest molybdenum in a concentrated muriatic solution of molybdic acid. The liquid becomes first blue, and afterwards a very deep red. When this last colour appears, add caustic ammonia to the solution, and the hydrated deutoxide of molybdenum will be precipitated. A still easier method is to dissolve chloride of molybdenum (obtained by passing a current of chlorine gas over hot molybdenum) in water, and precipitate the solution by ammonia. Another method is to digest a mixture of molybdic acid, and copper in muriatic acid, till all the molybdic acid be dissolved. The liquid, which has a dark red colour, is to be mixed with a sufficient quantity of ammonia to keep the copper in solution, while it throws down the hydrated deutoxide of molybdenum.

Hydrate of.   This hydrate has exactly the appearance of peroxide of iron. According to Berzelius, it is soluble in water. The solution has a yellow colour. Hence it cannot be washed with pure water. But it may be washed with water holding sal ammoniac in solution, and the sal ammoniac may be ultimately removed by alcohol. It should be dried in vacuo, over sulphuric acid. The saturated aqueous solution of this deutoxide has a deep red colour. When kept for two or three weeks in a close vessel, it assumes the form of a jelly, without losing its transparency. This aqueous solution reddens litmus paper. It has a weak astringent taste, and leaves a metallic impression in the mouth.

When dried it has a very dark brown colour, and has lost the property of dissolving in water. When heated in vacuo it lets go its water, and the anhydrous deutoxide remains no longer soluble in acids. The caustic alkalies do not dissolve it, but it is soluble in the alkaline carbonates. After being once precipitated, it is no longer soluble, except very feebly, in these carbonates. When an excess of an alkaline carbonate is poured into a salt of molybdenum, containing this oxide for a base, all the precipitate at first formed, is redissolved. The alkaline bicarbonates dissolve still more of it than the carbonates. When a solution of this oxide in carbonate of potash is left to itself for some time, the oxide is gradually acidified, and molybdate of potash formed.

Berzelius found that 100 parts of this oxide, when digested in nitric acid, were converted into 112·55 parts of molybdic acid. Now it will appear immediately, that molybdic acid contains $\frac{1}{3}$d of its weight of oxygen. Consequently 112·55 parts of molybdic acid contains 37·5 parts of oxygen, and 100

deutoxide of molybdenum, is a compound of 75 parts molybdenum and 25 oxygen. Hence we have the oxygen in deutoxide to that in molybdic acid as 25 to 37·5, that is as 2 to 3. Hence deutoxide must be a compound of

1 atom molybdenum	. .	6
2 atoms oxygen	. . •	2
		8

and its atomic weight must be 8.

3. Molybdic acid is obtained most easily from native molybdena, by roasting it for some time, and then dissolving the gray residue in ammonia. The solution is to be concentrated and then filtered. A little caustic ammonia being added to the liquid, after it has been sufficiently concentrated, it is to be set aside to crystallize. These crystals being exposed to a gentle heat in an open crucible, the ammonia is driven off, and pure molybdic acid remains behind; or deutoxide of molybdenum may be dissolved in nitric acid, the solution evaporated to dryness, and the dry residue exposed to a heat sufficiently strong to drive off all the nitric acid.

Molybdic acid thus prepared, is a white light porous matter, which, when agitated in water, divides itself into crystalline scales, having a silky lustre when exposed to the direct rays of the sun. At a red heat it melts into a deep yellow liquid, straw yellow and in crystalline scales when cold. Its specific gravity, as determined by Bergman, is 3·46. In close vessels it is fixed at a red heat; but in an open vessel it begins to smoke and volatilize as soon as it enters into fusion. If we heat it in a platinum crucible, covered with a concave lid, containing water, it may be sublimed in yellow scales, which attach themselves to the inside of the vessel. It dissolves very sparingly in water; to which, however, it communicates the property of reddening vegetable blues. This solution has a weak metallic taste. Water takes up about $\frac{1}{570}$th part of its weight of this acid. No hydrated molybdic acid is known. Before calcination it is soluble in acids, with which it combines, forming a kind of salts. It dissolves when boiled with bitartrate of potash, even after having been calcined.

From the experiments of Bucholz, it appears that when 100 parts of molybdenum are converted into molybdic acid, they unite with 49 or 50 parts of oxygen. I found that 15 grains of anhydrous molybdate of potash, when mixed with 20·75 grains of anhydrous nitrate of lead, were deprived exactly of

all their molybdic acid, which precipitated in the state of molybdate of lead. The residual liquid contained no lead nor molybdic acid. Now 20·75 parts of nitrate of lead contain 14 parts of oxide of lead, which is the equivalent of an atom. Therefore 14 oxide of lead must have combined with an atom of molybdic acid.• 15 parts of molybdate of potash must have contained an atom of molybdic acid, and this atom must have been united to an atom or 6 of potash. Consequently molybdate of potash is a compound of

1 atom molybdic acid	.	.	9
1 atom potash	.	.	6
			—
			15

It is evident from this that an atom of molybdic acid weighs 9. And as Bucholz has shewn that ⅓d of its weight is oxygen, it follows that it is a compound of 6 molybdenum and 3 oxygen. 6 then is the atomic weight of molybdenum, and molybdic acid is a compound of

1 atom molybdenum	.	.	6
3 atoms oxygen	.	.	3
			—
			9

Supposed molybdous acid.   4. There is another compound to which Bucholz gave the name of *molybdous acid*, and which has a blue colour. It was obtained by him by the following process: Mix together 1 part of molybdenum in powder and 2 parts of molybdic acid, and triturate them in a porcelain mortar made into a pap with hot water till the mixture becomes blue, then add 8 or 10 parts of water, and boil the whole for a few minutes. Filter the solution, and evaporate in a temperature not exceeding 120°. The blue oxide remains in the state of a fine powder. If the whole of the mixture of molybdenum and molybdic acid be not dissolved, the process may be repeated with the residue as often as is necessary. It may be prepared also by triturating for a long time with water, three parts of deutoxide of molybdenum, and four parts of molybdic acid, and then boiling the mixture. The blue liquor is gently evaporated over a little metallic molybdenum.

When we drop a solution of bichloride of molybdenum into a concentrated solution of molybdate of ammonia, the blue matter precipitates under the form of a powder. When we filter, the blue matter is left on the filter in a state very similar to indigo. It may be washed by a solution of sal ammoniac, in

which it is insoluble. It is soluble in water and also in alcohol. The aqueous solution is a fine blue. I found that when set aside for some time it became colourless, while a quantity of molybdic acid was deposited at the bottom of the phial. In a dry state it may be kept as long as you please. When heated in vacuo it gives out water, acquires a brownish blue colour, and loses its solubility in water. It is precipitated from water by sal ammoniac. It dissolves in acids and forms a fine blue solution. When evaporated to dryness, a thick blue matter is obtained, which gradually loses its colour.

The aqueous solution of this blue substance is instantly deprived of its colour by the addition of an alkali. Deutoxide of molybdenum is thrown down, and there remains in solution an alkaline molybdate. These phenomena seem to leave no doubt that Berzelius's opinion respecting the nature of this blue matter, is correct. It is a solution of deutoxide of molybdenum in molybdic acid. Supposing it to be a neutral molybdate of molybdenum, its constituents will be

1 atom molybdic acid 9
1 atom deutoxide of molybdenum . . 8
                                    ——
                                    17

So that it consists of 2 atoms of molybdenum united to 5 atoms of oxygen. But Berzelius affirms, though apparently entirely from theoretical consideration, that it is a compound of 83 molybdic acid, and 17 deutoxide. That is to say of

4½ atoms molybdic acid . . 40·5
1 atom deutoxide . . 8
                          ——
                          48·5

It is plain that Bucholz's opinion respecting its nature cannot be correct, otherwise it would be identical with deutoxide of molybdenum, which possesses very different properties.

III. Chlorine and molybdenum unite in three proportions, forming three chlorides, analogous in their constitution to the three oxides.

1. Bichloride of molybdenum is the most easily obtained. When molybdenum is heated in chlorine gas, it takes fire, and burns, forming a dark red vapour, which condenses in the cold part of the apparatus, in dark gray crystals, quite similar to iodine in appearance. These crystals constitute bichloride of molybdenum. It melts when slightly heated, and is easily sublimed. On congealing, it crystallizes. When exposed to

the air it gives out vapours, and soon begins to deliquesce. The solution is at first black; it then becomes bluish green, and when diluted with water, it becomes deep red, and at last yellow. When kept in a vessel containing common air it absorbs oxygen, a white sublimate appears, which is perchloride of molybdenum. When put into water, this deutochloride acts upon the liquid with such violence, that an effervescence appears at the point of contact, as if a gas was separating, which, however, is not the case. When a little of the chloride is mixed with much water, the liquid becomes green or blue from the oxidizing action of the air. Berzelius informs us (but he does not appear to have subjected it to analysis) that this chloride is a compound of

2 atoms chlorine	.	.	9
1 atom molybdenum	.	.	6
			——
			15

So that its atomic weight is 15, and it is analogous to the deutoxide of molybdenum.[*]

Chloride.   2. When metallic molybdenum is heated in the vapour of deutochloride of molybdenum, it absorbs the vapour, and is converted into a conglutinated dark red matter, which is the protochloride of molybdenum. When this matter is digested in water, only a little protomuriate of molybdenum is dissolved. The residual matter still retains its colour, and is insoluble in water and muriatic acid; but when treated with an alkaline hydrate, muriate of the alkali is formed, and protoxide of molybdenum thrown down. It is obvious from this, that the chloride is a compound of

1 atom chlorine	.	.	4·5
1 atom molybdenum	.	.	6
			——
			10·5

and that its atomic weight is 10·5. When heated to redness in vacuo, it sublimes into a dark green matter, soluble in water and muriatic acid. But when air has access to it, the sublimate is tile red and insoluble in water; but equally resolvable by an alkaline hydrate into muriatic acid and protoxide of molybdenum. The nature of this green sublimate is quite the same.[†]

Terchloride.   3. When anhydrous deutoxide of molybdenum is heated in

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[*] Kongl. Vetensk. Acad. Handl. 1825, p. 154.   [†] Ibid. p. 165.

dry chlorine gas, a yellowish white sublimate rises, and molyb-
dic acid remains behind.   This sublimate is a perchloride of
molybdenum composed of

3 atoms chlorine	. .	13·5
1 atom molybdenum	. .	6
		19·5

The sublimate is in soft crystalline plates.   It does not melt
when heated, and is less volatile than the bichloride, but sub-
limes easily under a red heat.   It is very soluble in water and
alcohol.   Its taste is astringent and metallic.*

IV. We are still unacquainted with the combinations of bro-
mine with molybdenum.

V. We are acquainted with two compounds of iodine and
molybdenum, analogous to the two oxides.   No compound of
iodine analogous to molybdic acid has been yet discovered.

1. The vapour of iodine does not act upon molybdenum
even at a red heat.   But the hydrated protoxide dissolves in
hydriodic acid, and forms a salt quite similar to the chloride.

2. In like manner, the hydrated deutoxide of molybdenum
dissolves in hydriodic acid, and when the solution is evapo-
rated, red crystals are obtained, constituting a deutoxide of
molybdenum.   The crystals by reflected light appear brown.
When this salt is heated to redness it is decomposed into
hydriodic acid and deutoxide of molybdenum.†

VI. Nothing is known respecting any combinations which
molybdenum may be capable of forming with hydrogen, azote,
carbon, boron, silicon, or phosphorus.

VII. We are acquainted with three compounds of sulphur
and molybdenum.   But as none of these is analogous to the
protoxide, protiodide, and protochloride, the probability is, that
a fourth sulphuret will hereafter be discovered containing less
sulphur than any of those at present known.

1. Bisulphide of molybdenum occurs native, and is well
known to mineralogists under the name of molybdena.   It is
soft, has a leaden colour, the metallic lustre, stains paper like
plumbago, but leaves a dark green streak on porcelain.   Its
specific gravity is 4·591.   It may be exposed to a very high
temperature in close vessels without undergoing any change.
But in the open air its sulphur is soon dissipated when heat is
applied, and the molybdenum acidified.   Nitric acid oxidizes

* Kongl. Vetensk. Acad. Handl. 1825, p. 170.
† Ibid. pp. 167 and 155.

it easily without dissolving it, while it is soluble in aqua regia. Caustic potash hardly acts upon it in the moist way, but when the two substances are fused together, a compound is formed which dissolves in water. This sulphide, according to the analysis of Bucholz, is a compound of

<div style="text-align:center">

1 atom molybdenum   .   .   6
2 atoms sulphur   .   .   4
                        —
                     10

</div>

Tersulphide.   2. *Tersulphide of molybdenum* may be obtained by passing a current of sulphuretted hydrogen gas through a concentrated solution of a molybdate in water. The gas is absorbed with avidity, and on adding an acid, tersulphide of molybdenum precipitates. It is under the form of a dark brown powder, which becomes quite black when dried. When distilled it gives out sulphur, and leaves bisulphide of molybdenum. When drawn along porcelain it leaves a brownish black line. It is scarcely soluble in caustic potash, but dissolves readily in sulphuret of potassium, and in the hydrosulphurets; at least when assisted by heat. We obtain the same tersulphide when we dissolve molybdic acid in a hydrosulphuret, and precipitate the solution by an acid. But the tersulphide in that case is often mixed with sulphur or with molybdic acid. Sulphuretted hydrogen gas when left in contact with molybdic acid, renders it first blue and then black.* The tersulphide is a compound of

<div style="text-align:center">

3 atoms sulphur   c   .   .   6
1 atom molybdenum   .   .   6
                        —
                     12

</div>

Quatersulphide.   3. Quatersulphide of molybdenum was first formed by Berzelius. It may be obtained by the following process: Prepare a combination of bisulphide of molybdenum with sulphuret of potassium.† To this must be added an excess of bisulphide of molybdenum, and the mixture must be boiled for a long time in a sufficient quantity of water. At a certain period the liquid becomes muddy, and a black powder precipitates. This powder is to be collected on a filter, and washed with cold water, till the liquid which passes through, when mixed with muriatic acid, lets fall a red precipitate and not a brownish black one.

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* Berzelius; Kongl. Vetensk. Acad. Handl. 1825, p. 300.
† This is a sulphur salt which will be described in a subsequent part of this work. It is a very beautiful crystallized salt.

Then boiling water is poured upon the black matter contained
on the filter, as long as any thing is dissolved.   A solution of
a dark red colour is obtained, into which an excess of muriatic
acid is to be poured.   A dark red, translucent, bulky precipi-
tate is obtained, which is to be washed on a filter.   It consti-
tutes quatersulphide of molybdenum.

When dried it is much less bulky, has the metallic lustre
and a gray colour, but when pounded assumes a cinnamon brown
colour.   This quatersulphide is a compound of

> 4 atoms sulphur   .   .   8
> 1 atom molybdenum   .   .   6
> ___
> 14*

VIII. We are still unacquainted with the combinations
which molybdenum may be capable of forming with selenium
and tellurium.

IX. When arsenic and molybdenum are melted together, Arsenict.
the whole of the arsenic sublimes; but when oxide of arsenic
is employed, a combination takes place, from which the arsenic
is not easily separable again.†

X. No attempt has hitherto been made to alloy antimony
with molybdenum; we do not therefore know whether these
two metals be capable of combining with each other.   Nor is
any thing known respecting the alloy of molybdenum and
chromium.

The salts of molybdenum have slightly poisonous qualities. Might form a dye.
Hitherto this metal has not been applied to any useful purpose.
Could it be procured in sufficient quantity it would be service-
able to the calico-printers by striking a blue upon cloth, which
would in all probability be much less easily altered than prus-
sian blue, at present applied as a colour on calicoes.   But the
great scarcity of this metal renders any useful application of it
very unlikely.   The method of dyeing blue by means of molyb-
denum is easy.   Apply a mordant consisting of protochloride
of tin to the cloth, and then pass it through a solution contain-
ing molybdic acid, molybdate of molybdenum is formed by the
action of the tin, and at the same time fixed upon the cloth.

SECTION XV.—OF TUNGSTEN.

There is a mineral found in Sweden of an opaque white History.

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* Berzelius ; Kongl. Vetensk. Acad. Handl. 1825, p. 314.
† Crell's Annals, iii. 368.

colour and great weight; from which last circumstance it got the name of *tungsten,* or *ponderous stone.* Some mineralogists considered it as an ore of tin, others supposed that it contained iron. Scheele analyzed it in 1781, and found that it was composed of lime and a peculiar earthy-like substance, which he called from its properties *tungstic acid.*[*] Bergman conjectured that the basis of this acid is a metal;[†] and this conjecture was soon after fully confirmed by the experiments of Messrs. D'Elhuyart, who obtained the same substance from a mineral of a brownish-black colour, called by the Germans *wolfram,*[‡] which is sometimes found in tin mines. This mineral they found to contain $\frac{65}{100}$ of tungstic acid; the rest of it consisted of manganese and iron. This acid substance they mixed with charcoal powder, and heated violently in a crucible. On opening the crucible after it had cooled, they found in it a button of metal, of a dark brown colour, which crumbled to powder between the fingers. On viewing it with a glass, they found it to consist of a congeries of metallic globules, some of which were as large as a pin-head. The metal thus obtained is called *tungsten.* The manner in which it is produced is evident: tungstic acid is composed of oxygen and tungsten; the oxygen combined with carbon, and left the metal in a state of purity.[§]

The experiments of the Elhuyarts were repeated in 1796 by Vauquelin and Hecht, in general with success; but they were unable to procure the metal completely fused, though this had been accomplished by the Spanish chemists.[||] Nor is this to be wondered at, as Dr. Pearson[¶] and Mr. Klaproth[**] had made the same attempt before them without succeeding. The fusion of this metal has been also accomplished by Messrs. Allen and Aitken of London. They succeeded by applying a strong heat to the combination of the oxide of tungsten and ammonia.[††] Since that time a set of experiments on tungsten has been published by Bucholz,[‡‡] some valuable investigations on the compositions of its oxides have been made by Berzelius,[§§]

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* Scheele, ii. 81.   † Ibid. ii. 91.
‡ Wolfram had been analyzed in 1761 by Lehmann. He imagined it a compound of iron and tin. See his Probierkunst, p. 8.
§ Mem. Thoulouse, ii. 141. This memoir has been translated into English.
|| Jour. de Min. No. xix. 3.   ¶ Transl. of the Chem. Nomenclature.
** Observ. on the Fossils of Cornwall, p. 77.
†† Aiken's Dictionary of Chemistry, ii. 445.
‡‡ Schweigger's Journal, iii. 1; and Annals of Philosophy, vi. 198.
§§ Annals of Philosophy, iii. 244.

and a most important set of experiments on its oxide and chlorides has been published by Wöhler.*

The following process, for which we are indebted to M. Wöhler, is the easiest method of obtaining tungsten in the metallic state.† Fuse together a mixture of wolfram and carbonate of potash in a crucible. Then digest the fused mass in water which will dissolve the tungstate of potash formed. To this solution add a quantity of solution of sal ammoniac in water, and evaporate the whole to dryness. Put the dry saline residue into a Hessian crucible, and heat till the sal ammoniac is entirely decomposed or dissipated. The residual matter being now dissolved in hot water, a heavy black powder separates which is oxide of tungsten. Let it be boiled in a weak solution of potash to remove a small quantity of bitungstate of potash that it may contain, and finally in pure water. When this powder is heated in an open crucible it takes fire, and is converted into tungstic acid.‡ The affinity of tungsten for oxygen not being very strong, it is easily reduced to the metallic state by passing a current of dry hydrogen gas over tungstic acid heated to redness in a glass tube. If bitungstate of potash be used instead of tungstic acid the excess of acid is easily reduced by hydrogen, and when the neutral salt is washed away by water the metallic particles remaining have more lustre than when tungstic acid is used.

1. Tungsten, called by some of the German chemists *scheelium*, and by Berzelius *wolframium*, is of a grayish-white colour, or rather like that of steel, and has a good deal of brilliancy. It is one of the hardest of the metals: for Vauquelin and Hecht could scarcely make any impression upon it with a file. It seems also to be brittle. Its specific gravity, according to the D'Elhuyarts, is 17·6; according to Allen and

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* Kongl. Vetensk. Acad. Handl. 1824, p. 101.

† It is merely a modification of Bucholz's process for obtaining tungstic acid, which is as follows : Mix 1 part of wolfram in fine powder with 2 parts of *subcarbonate of potash ;* keep the mixture melted in a crucible for an hour, stirring it occasionally. Then pour it into an iron cone. Before the mass be quite cold, reduce it to powder, and boil water on it repeatedly till the liquid comes off tasteless. Mix all the watery solutions together, and pour muriatic acid into them as long as any precipitate appears. Wash the precipitate ; dissolve it in boiling carbonate of potash, precipitate it again by muriatic acid, wash the precipitate, and dry it upon filtering paper. It is pure tungstic acid. See Jour. de Chim. iii. 220.

‡ Kongl. Vetensk. Acad. Handl. 1824, p. 99.

Aiken, 17·33.* Bucholz found it 17·4,† which being nearly a mean of the preceding results, may be taken as very near the truth. It is therefore the heaviest of the metals after gold, platinum, and iridium. It requires for fusion a very high temperature. It seems to have the property of crystallizing on cooling, like all the other metals; for the imperfect button produced by Vauquelin and Hecht contained a great number of small crystals. It is not attracted by the magnet.

Oxides.　　II. When heated in an open vessel, it gradually absorbs oxygen, and is converted into an oxide. Tungsten seems capable of combining with two different proportions of oxygen, and of forming two different oxides; the *brown* or *black*, and the *yellow* or *tungstic acid*.

Brown oxide.　　1. Brown oxide of tungsten seems to have been observed by Bucholz; but its nature was first accurately investigated by Berzelius. He obtained it by putting a quantity of tungstic acid in a glass tube, heating it to a very low red heat, and passing through it while in that state a current of hydrogen gas. Water was formed, and the acid deprived of a portion of its oxygen. The oxide formed had a flea-brown colour, and when heated in the open air takes fire and burns like tinder, and is converted into tungstic acid. The process of Wöhler given at the beginning of this section, furnishes this oxide also; but the colour is black instead of brown, owing doubtless to a different state of aggregation.

When obtained by the action of hydrogen gas on tungstic acid, it has a brown colour and the metallic lustre, and if we employ crystallized tungstic acid (obtained by decomposing tungstate of ammonia in an open vessel) it has a crystalline texture. It has then a good deal of the appearance of copper. If dilute muriatic acid be poured upon tungstic acid, and a plate of zinc be put into the liquid, the oxide of tungsten is deposited in beautiful copper red flocks. But when thus prepared it cannot be preserved; for it speedily absorbs oxygen, and is converted into tungstic acid. The oxide prepared by the dry way may be kept without alteration. When heated it burns like tinder, and is converted into tungstic acid. Wöhler found that 100 parts of the black oxide when thus heated absorb 8 parts of oxygen during the conversion into tungstic acid. This agrees very well with the previous experiments of

* Aiken's Dictionary of Chemistry, ii. 445.
† Annals of Philosophy, vi. 205.

Berzelius on the brown oxide, showing that the difference in colour is not owing to any difference in constitution. Now it appears from the experiments of Berzelius, that 100 parts of tungsten, when converted into tungstic acid, unite with from 25·32 to 25·355 of oxygen.* It is easy to deduce from these two sets of experiments, that the two oxides of tungsten are composed as follows :

			Metal.	
Brown oxide of	.	.	100	+ 16·04 oxygen
Tungstic acid	.	.	100	+ 25·33

Now 16·04 is to 25·33 very nearly as 2 to 3. The probability from this is, that brown oxide of tungsten is a compound of 1 atom metal and two atoms oxygen, while tungstic acid contains 3 atoms oxygen. This would make the atomic weight of tungsten 12·5 if we calculate from the oxide, and 11·848 if we calculate from the acid. I am disposed to consider the first number as the correct one, and to make the atomic weight of tungsten 12·5.

In my First Principles I have shown that a tungstate of soda which I formed by boiling tungstic acid in a solution of carbonate of soda, till it refused to take up any more, was a compound of

Tungstic acid	.	.	18·75
Soda	.	. .	4
Water	. .	.	.	6·75
			29·50

The soda and water amounting to exact atomic proportions, I was led to consider 18·75 as the atomic weight of tungstic acid. But Wöhler has since proved that soda is capable of combining with an excess of tungstic acid. This destroys the legitimacy of the consequences which I drew from my analysis. For I may probably have analyzed a sesquitungstate. It will be safest then, till a greater number of tungstates have been subjected to analysis, to deduce the atomic weight of this body from the experiments of Berzelius, though it is evident that these experiments are not perfectly accurate.

Wöhler has discovered a curious compound of oxide of tungsten and soda, which would deserve to be farther investigated. His method was to fuse tungstate of soda, and dissolve in it as much tungstic acid as it would take up. Over this supersalt heated to redness in a glass tube, dry hydrogen gas

* Kongl. Vet. Acad. Handl. 1824, p. 324.

was made to pass.   It gradually assumed the colour of copper. After washing out the tungstate of soda, the new compound remains crystallized in cubes, and having a fine golden colour and the metallic lustre.   It is not acted on by water, sulphuric acid, nitric acid, nor aqua regia, nor by alkaline solutions. Fluoric acid dissolves it.   Oxygen gas, chlorine, and sulphur, decompose it when the temperature is raised pretty high. According to the analysis of Wöhler it is composed of

Oxide of tungsten . .	87·6
Soda	12·4

Now this corresponds very nearly to

2 atoms oxide of tungsten . .	29
1 atom soda	4
	——
	33

It would appear from this that oxide of tungsten, in this compound, acts the part of an acid.*

Tungstic acid.   2. The easiest method of obtaining tungstic acid is to expose the black oxide of Wöhler to a red heat.   It burns like tinder, and is converted into tungstic acid.

When we form tungstic acid by fusing wolfram with potash, and precipitating the tungstic acid from the tungstate of potash formed, by means of nitric acid, Bucholz has shown that it is never free from potash and silica.   Berzelius gives the following process for purifying it : Dissolve the impure tungstic acid in hydrosulphuret of ammonia, filter the solution, and add nitric acid to it.   A dark brown precipitate falls, consisting of sulphuret of tungsten.   Wash it with water holding a little nitric acid, as it is slightly soluble in pure water.   Dry it and roast it in a gentle heat.   Tungstic acid remains of a pale lemon yellow colour.

When strongly heated it becomes green, as it does also when exposed to the rays of the sun.   Its specific gravity, as determined by Mr. Harepath, is 5·274; but Berzelius makes it as high as 6·12.   It is tasteless, insoluble in water; but very soluble in the caustic alkalies.   Tungstic acid has the property of combining with other acids.   When precipitated from tungstate of ammonia by an acid, the precipitate is always a compound of tungstic acid and of the acid employed to throw it down.   Sulphuric acid forms with it a white magma insoluble in sulphuric acid, soluble in water, but again precipitated by an

* Kongl. Vet. Acad. Handl. 1824, p. 103.

acid. The compound of tungstic acid and nitric acid is lemon
yellow, and imperfectly soluble in water. The compound of
this acid with muriatic resembles its compound with sulphuric.

When tungstic acid is partially reduced it becomes blue like
molybdic acid. This happens when zinc is put into a liquid
containing tungstic acid, or when tungstate of ammonia is
decomposed by distillation in a retort. In this last case an
indigo blue powder is obtained, which Berzelius assures us is a
tungstate of tungsten composed of

Tungstic acid	.	.	81·1
Oxide of tungsten	.	.	18·9
			————
			100

This is exactly

4 atoms tungstic acid	.	.	62
1 atom tungstic oxide	.	.	14·5
			———
			76·5

The powder is therefore a quatertungstate of tungsten.
It has been already stated that tungstic acid is a compound of

1 atom tungsten	.	.	12·5
3 atoms oxygen	.	.	3
			————
			15·5

So that its atomic weight is 15·5.

III. The chlorides of tungsten have been investigated by
Wöhler, who has shown that they amount to three.

1. Bichloride of tungsten is obtained, when metallic tung-
sten is heated in a current of chlorine gas. It takes fire and
forms a chloride of a deep red colour, which sublimes and depo-
sites itself in the form of fine needles interlaced together. It
melts at a low heat, and is converted into a red vapour of a
much deeper colour than the fumes of nitrous acid. Water
decomposes it into oxide of tungsten and muriatic acid.
Hence it is evidently a compound of

2 atoms chlorine	.	.	9
1 atom tungsten	.	.	12·5
			————
			21·5

And its atomic weight is 21·5. Caustic potash decomposes it
with the evolution of hydrogen gas. Ammonia also dissolves
it with the evolution of a little gas. When the solution is

heated, brown oxide of tungsten is deposited, and the liquid becomes colourless.

Terchloride.   2. Terchloride of tungsten is formed, when oxide of tungsten is heated in a current of chlorine gas. The oxide takes fire, leaves a residue of tungstic acid, and the chloride sublimes in yellowish white plates, resembling native boracic acid. This chloride is very volatile, and rises in the state of a yellow vapour without melting. Its smell is suffocating, and when exposed to the air it absorbs moisture, and is resolved into muriatic acid and tungstic acid. Hence its constituents must be

3 atoms chlorine	.	.	13·5
1 atom tungsten	.	.	12·5
			26

When heated on platinum foil over a spirit lamp, the vapour exhaled is decomposed by the water from the flame, and tungstic acid appears in a white smoke, like flowers of zinc.

3. Wöhler obtained a third chloride by heating sulphuret of tungsten in chlorine. It has a much finer red colour than the bichloride, and forms long transparent needles. When heated it gives out a vapour having the colour of nitrous acid. When exposed to the air, it is rapidly changed into muriatic acid and tungstic acid. In water it swells up, heat is given out, and it is instantly converted with a hissing noise into muriatic and tungstic acids. The difference between the composition of this chloride and the preceding has not been ascertained.*

IV. Nothing is known respecting the borides and iodides of tungsten; nor do we know whether it combines with hydrogen, azote, carbon, boron, or silicon.

V. Pelletier ascertained that tungsten combines with phosphorus; but the properties of the phosphuret were not examined.†

Sulphuret.   VI. Tungsten combines with two proportions of sulphur, forming compounds analogous to the oxide and acid of tungsten.

1. Bisulphuret of tungsten was obtained by Berzelius. He obtained it by mixing tungstic acid with four times its weight of sulphuret of mercury, putting the mixture into a crucible, covering its surface with charcoal powder, and exposing it for half an hour to a violent heat. It may be obtained also by passing a current of sulphuretted hydrogen gas over tungstic

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* Kongl. Vetens. Acad. Hand. 1824, p. 108.
† Ann. de Chim. xiii. 137.

acid heated to whiteness in a porcelain tube. Bisulphuret of
tungsten thus formed is a grayish black powder, which when
rubbed upon a polished hematite assumes a beautiful metallic
lustre. Berzelius* found it a compound of

Tungsten . . . •100
Sulphur . . 33·26

Thus it contains twice as much sulphur as the brown oxide
does oxygen. It is therefore a compound of 1 atom tungsten
+ 2 atoms sulphur.

2. Tersulphuret of tungsten is obtained by dissolving tung- Tersulphuret.
stic acid in a hydrosulphuret, and precipitating the solution by
an acid added in excess, washing and then drying the precipi-
tate. Its colour is liver brown, but it becomes black in drying.
It is soluble in water, and boiling water takes it up in consid-
erable quantity, and assumes a yellowish brown colour. Sal
ammoniac throws down the greatest part of it, but not the
whole. When the aqueous solution is much concentrated by
evaporation, it deposites the tersulphuret in the state of a
transparent yellow matter, which, by drying, is converted into
a powder less soluble in water than formerly. When boiled
with water in a retort, a small quantity of sulphuretted hy-
drogen is given out, owing probably to the acidification of a
little of the tungsten. When heated it gives out a little water
and sulphuretted hydrogen, then sulphur sublimes and bisul-
phuret remains. It dissolves slowly in ammonia and the
caustic fixed alkalies. The alkaline carbonates dissolve it
without heat, assume a brown colour, and are converted into
bicarbonates. According to the analysis of Berzelius, to whom
we are indebted for our knowledge of this sulphuret, it is a
compound of

3 atoms sulphur . . 6
1 atom tungsten . . 12·5
_____
18·5

VII. We know nothing of the combinations which tungsten
may be capable of forming with selenium, arsenic, tellurium,
chromium, and molybdenum. 100 grains of tungsten were
heated with 50 grains of antimony by the Elhuyarts; the
button was of a dark brown colour, shining, something spongy,
harsh, and broke in pieces easily: it weighed 108 grains. This
was an alloy of

* Annals of Philosophy, iii. 245.

2 B

8 atoms tungsten	.	.	100
1 atom antimony	.	.	8
			108

According to the trials of M. C. G. Gmelin, tungsten, even when in the state of an acid, has no injurious effect on the animal economy, when taken internally.

SECTION XVI.—OF COLUMBIUM.

In the year 1801, while Mr. Hatchett was engaged in arranging some minerals in the British Museum, a dark-coloured heavy substance attracted his attention, on account of some resemblance which it bore to *chromate of iron.* The specimen was small. It was described in Sir Hans Sloane's catalogue as " a very heavy black stone with golden streaks;" and it appears that it was sent, along with various specimens of iron ores, to Sir Hans Sloane by Mr. Winthrop of Massachusetts. Its colour was a dark brown gray; its longitudinal fracture imperfectly lamellated, and its cross fracture showed a fine grain. Its lustre was glassy, and in some parts slightly metallic. It was moderately hard, but very brittle. By trituration it yielded a powder of a dark chocolate brown, not attracted by the magnet. Its specific gravity at the temperature of 65°, was 5·918.

By an ingenious analysis of this mineral, Mr. Hatchett ascertained that it was composed of 1 part of oxide of iron, and rather more than 3 parts of a white coloured substance which possessed the properties of an acid, and exhibited undoubted proofs of being composed of oxygen united to a metallic basis. Mr. Hatchett demonstrated, that it differs from all the metallic acids hitherto examined; of course its metallic basis must be also peculiar, and required a distinct name. Accordingly he gave it the name of *columbium.*

Soon after Mr. Hatchett's discovery a metallic substance was detected in Sweden by Mr. Ekeberg, differing from every other with which he was acquainted. To this metal he gave the name of *tantalum,* and to the minerals from which he obtained it the names of *tantalite* and *yttrotantalite.** In the year 1809, Dr. Wollaston procured specimens of the Swedish minerals, and by a careful comparison of the new oxide which it contained with the new oxide in the mineral in the British Museum, analyzed by Mr. Hatchett, he demonstrated that *colum-*

* Vetenscaps Academiens Handlingar, 1802, p. 268.

bium and *tantalum* are one and the same substance.* In the
year 1815, Assessor Gahn of Fahlun and Professor Berzelius
discovered various new minerals in the neighbourhood of
Fahlun, containing tantalum. Berzelius analyzed these mine-
rals, and attempted to reduce the oxide to the metallic state by
heating it violently in a charcoal crucible. The matter which
he got was gray and agglutinated together, and did not con-
duct electricity.† He took it at first for metallic columbium;
but found afterwards that it was only the oxide of that metal.
He resumed his labours in 1824, and succeeded in obtaining
columbium in the metallic state.‡

Perhaps the simplest method of extracting the oxide of
columbium or columbic acid from the mineral called *tantalite*
is the method employed by Dr. Wollaston, which is as fol-
lows: Mix together 1 part of tantalite with 5 parts of carbon-
ate of potash and 2 parts of borax, and fuse the mixture in a
platinum crucible. Soften the fused mass with water, and
then digest it in muriatic acid. The iron and manganese
which existed in the mineral combined with the oxide of tan-
talum are dissolved, and nothing remains but the columbium
in the state of a white powder.§

To obtain columbium from this acid Berzelius dissolved it in
fluoric acid, and formed what he considered as a fluocolumbic
acid. This acid was saturated with potash, and the solution
evaporated to dryness. The dry salt freed from water was
treated with potassium in the way formerly described as prac-
tised by him to obtain silicon. The columbium is reduced at
an incipient red heat, with the evolution of light. Water
removes the fluate of potash, and leaves the columbium in a
state of purity.

Columbium thus obtained is a black powder, which cannot Properties.
be fused though exposed to a very high temperature. Under
the burnisher it assumes the metallic lustre, and an iron gray
colour. It does not conduct electricity. This led Berzelius

* Phil. Trans. 1809, p. 246.
† Afhandlingar, iv. 252, 262.
‡ Kong. Vetensk. Acad. Handl. 1824, p. 282.
§ Berzelius found *tungsten* in some of the tantalites from the neighbour-
hood of Fahlun, which he examined, and he states in a letter to me, (Annals
of Philosophy, iv. 467,) that Ekeberg found the columbic acid of Hatchett,
which he examined, a mixture of oxides of tantalum and tungsten. But I
doubt the accuracy of this statement, because Dr. Wollaston found no
tungsten in columbite; nor could he detect any, though he made a new
trial at my request after receiving Berzelius's letter.

to examine the yellow crust which covers the agglutinated matter obtained when columbic acid is violently heated in charcoal. He found it to conduct electricity perfectly, and therefore concluded that it was metallic columbium. The colour of this metal then is white, with a shade of yellow.

Columbium is not altered by exposure to the air. When heated it takes fire considerably under a red heat, glows vividly, but without flame, and is converted into columbic acid. Sulphuric, nitric, and muriatic acids, and even aqua regia, have very little action on it. Fluoric acid dissolves it with the disengagement of hydrogen gas, and the evolution of heat. The solution takes place still more rapidly in a mixture of fluoric and nitric acids. Caustic potash does not act upon it in the humid way; but when fused with it the metal is oxidized.

Oxides. II. From the experiments of Berzelius, it appears that columbium combines with two proportions of oxygen, forming an oxide and an acid.

Protoxide. 1. Oxide of columbium may be obtained by putting columbic acid into a charcoal crucible, and exposing it for an hour and a half to the heat of a forge. The matter is much reduced in bulk, is agglutinated together into a gray porous mass, the specific gravity of which, as determined by Dr. Wollaston, is 5·61. Under the burnisher it assumes somewhat of the metallic lustre. It is easily triturated into a brown coloured powder. Its particles are hard enough to scratch glass. It is not acted upon by any acid; but when fused with caustic potash it is converted into columbic acid, which unites with the potash. It detonates with nitre. It exists native in a peculiar species of columbite at Kimito in Finland, which has a specific gravity of 7·9, and gives, when triturated, a cinnamon brown colour.

Berzelius found that when this oxide of columbium was converted into columbic acid, 100 parts of it absorbed in different experiments 3·5, 4, and 4·2 parts of oxygen. The mean of which is 3·9 oxygen. But by an analysis of sulphuret of columbium, he showed that 100 parts of it, when converted into columbic acid, became 89·57 parts. Now, if we consider the sulphuret to contain as many atoms of sulphur as columbic acid does of oxygen, (and from the way in which it was formed, this must be the case,) then, as the atom of sulphur is just double that of oxygen, it is clear that 10·43, the difference between the weight of the sulphuret and acid, must be equal to the quantity of oxygen in 89·57 parts of columbic acid. Hence 100 columbic acid must contain 11·64 parts of oxygen, or it must be a compound of

Columbium   .   .   100

Oxygen ·   .   .   13.17

Now as 100 oxide of columbium becomes 103·9 when converted into columbic acid, it is clear that it must contain 8·19 parts of oxygen, and consequently oxide of columbium must be a compound of

Columbium   .   .   100

Oxygen   .   .   8·81

Now the numbers 8·81 and 13·17 are to each other nearly as 2 to 3. It is obvious from this, that oxide of columbium must be a compound of 1 atom columbium and 2 atoms oxygen, while columbic acid consists of an atom of columbium united to 3 atoms oxygen.*

The numbers 8·81 and 13·17 not being exactly in the ratio of 2 to 3, it is evident that the experiments are not quite accurate. The safest mode of proceeding will be to adopt 13·17 as probably the most correct: dividing this sum by 3, the quotient is very nearly 4·39, which gives us the weight of an atom of oxygen, that of columbium being 100. Dividing 100 by 4·39, we obtain 22·77 for the atomic weight of columbium. As the oxide of columbium employed by Berzelius does not seem to have been perfectly pure (for he considered it as having contained a little manganese), we can have no hesitation in making the atomic weight of columbium 22·75. Consequently Atomic weight that of oxide of columbium will be 24·75.

2. Columbic acid may be obtained by the process described Columbic acid. at the beginning of this section, or we may employ the more elaborate process of Berzelius, which is as follows: Reduce *tantalite* to an exceedingly fine powder, and mixing it with 8 times its weight of dry bisulphate of potash, heat it to redness in a platinum crucible, and continue the heat till it flows quite liquid, and till all the powder of tantalite has disappeared. Then reduce it to powder, and boil it with water till that liquid refuses to take up any thing more. The sulphuric acid in excess in the bisulphate dissolves the oxides of iron and manganese of the tantalite, which solutions are carried off by the water, while the columbic acid is left behind in the state of a white powder. But it is not quite pure; for it retains a portion of peroxide of iron, sometimes peroxide of tin, and even tungstic acid is occasionally present in it. To purify it from these foreign bodies, it must be digested in hydrosul-

* Kongl. Vetensk. Acad. Handl. 1824, p. 289.

phuret of ammonia, which dissolves the peroxide of tin and
the tungstic acid, and converts the iron into sulphuret, while at
the same time the columbic acid becomes green or black. Wash
it with water containing a little hydrosulphuret of ammonia to
prevent the iron from being oxidized. Then boil it in concen-
trated muriatic acid till it becomes quite white. The iron is dis-
solved, and the columbic acid remains behind in a state of purity.

Columbic acid thus prepared is a white tasteless powder,
which reddens litmus paper. When heated it gives out water,
and when anhydrous no longer acts upon litmus paper. Its
specific gravity, according to Berzelius, is 6·5. The hydrated
acid, according to Berzelius, is a compound of

$$
\begin{array}{lll}
\text{1 atom acid} & . \quad . & 25\cdot75 \\
\text{3 atoms water} & . \quad . & 3\cdot375 \\
\hline
& & 28\cdot125
\end{array}
$$

By allowing columbic acid to dry in the open air on the filter,
I obtained a hydrate composed of

$$
\begin{array}{lll}
\text{1 atom acid} & . \quad . & 25\cdot75 \\
\text{11 atoms water} & . \quad . & 12\cdot375 \\
\hline
& & 37\cdot125
\end{array}
$$

Columbic acid is soluble by fusion in bisulphate of potash;
but it precipitates when the salt is digested in water. It dis-
solves in an aqueous solution of quadroxalate of potash. The
solution is colourless, and the alkalies throw down the columbic
acid. This solution enables us easily to determine whether
the columbic acid contains tungstic acid. If it does, the
saturated solution gelatinizes on cooling, and when a piece of
zinc or tin is put into it, the colour becomes blue. I found it
to dissolve in sulphuric and muriatic acids only in a minute
proportion. This was the case also with oxalic and tartaric
acids. It has not the property of saturating these bodies, or
of uniting with them in definite proportions. After being
exposed to a red heat, it is quite insoluble both in alkalies and
acids, and to recover its solubility we must fuse it with caustic
potash, or with bisulphate of potash.

From the experiments of Berzelius, related in a preceding
part of this section, this acid appears to contain three atoms of
oxygen, and its atomic weight is obviously 25·75.

I found that columbic acid combines with soda, and forms a
beautiful salt, crystallized in fine silky scales, like boracic acid.
This salt rendered cudbear paper purple, and therefore acted

as an alkali. But this property was not removed by digesting it in alcohol. I found the composition of this salt to be

Columbic acid	. .	19
Soda	. . .	4
Water	, .	11·25

$$34·25*$$

I.concluded from this analysis that the atomic weight of columbic acid is 19. The only objection that can be made to this conclusion is, that my salt might have contained an excess of soda. For on the supposition that the atomic weight of columbic acid is 25·75, then my salt would have been a compound of

1 atom columbic acid	. .	25·75
$1\frac{1}{3}$ atom soda	. .	5·33
14 atoms water	. .	15·75

$$46·83$$

It would be necessary to clear up this point by analyzing some more of the salts of columbic acid before we could venture to make use of 19 as the true atom of columbic acid. But the scarcity of this rare substance puts it out of our power to make the requisite researches on it. I am rather inclined to adopt the number 19. My analysis, however, was made upon too small a scale for very great accuracy, though I expended on it all the columbic acid which was in my possession.

III. When columbium is heated in chlorine gas, it takes fire and burns brilliantly, and is converted into a vapour resembling chlorine. This vapour condenses on the colder parts of the apparatus into a white matter with a slight shade of yellow, resembling meal in appearance. When moistened with water a hissing noise is produced, and heat evolved, while at the same time the chloride is converted into muriatic and columbic acid. It is obvious from this that the compound is a terchloride, composed of

3 atoms chlorine	. .	13.5
1 atom columbium	. .	22·75

$$• 36·25†$$

IV. No attempts have been made to obtain the bromide or iodide of columbium.

* First Principles, ii. 78.
† Kongl. Vetensk. Acad. Handl. 1824, p. 288.

V. Hydrated columbic acid dissolves readily in fluoric acid. When the solution is concentrated by keeping it in the temperature of 86°, crystals are formed in it. These dissolve in water, and are considered by Berzelius, who obtained them, as a combination of fluoric and columbic acid. On that account he has given them the name of *hydrofluocolumbic acid.* They effloresce in the air, and then lose their property of dissolving in water. When the aqueous solution is evaporated to dryness in a gentle heat, a matter like white enamel is obtained quite the same as the effloresced crystals. Berzelius considers this as a fluoride of columbium. In the present state of our knowledge this can only be looked upon in the light of a conjecture. The hydrofluocolumbic acid unites with bases and forms a class of salts, a few of which have been examined.

VI. We are unacquainted with the compounds which columbium may be capable of forming with hydrogen, azote, carbon, boron, silicon, and phosphorus.

Sulphuret. VII. Sulphuret of columbium was first obtained by M. H. Rose. He procured it by heating columbic acid to whiteness and passing over it a current of the vapour of bisulphuret of carbon. The carbon is converted into carbonic oxide by uniting with the oxygen of the columbic acid : a portion of the sulphur is separated, and the rest unites with the columbium. When the bisulphuret of carbon issues undecomposed from the other extremity of the tube, it is a proof that all the columbic acid is converted into sulphuret.* The apparatus is then allowed to cool without admitting air to the sulphuret.

This sulphuret has a gray colour and a pulverulent form. It has the metallic lustre and a crystalline appearance, having a very considerable resemblance to plumbago. It feels soft, and is a conductor of electricity. When heated to incipient redness it takes fire, the sulphur burns with a blue flame and columbic acid remains behind united to a small quantity of sulphuric acid. When exposed for a long time to the action of chlorine gas it becomes hot, and unites with the chlorine. This combination is hastened by the application of heat. Chlorides of sulphur and columbium are formed. This sulphuret is not acted on by nitric, sulphuric, muriatic, nor fluoric acids. Aqua regia decomposes it at a boiling heat, dissolving sulphuric acid and a small quantity of columbic. It is dissolved also by a mixture of nitric and fluoric acids. It is not acted on by an aqueous solution of caustic potash. But when fused

* Gilbert's Annalen der Physik. lxxiii. 139.

with that alkali, an orange coloured mass is obtained.   In water
this matter dissolves, leaving sulphuret of columbium in the
state of a black powder.* This sulphuret has not been analyzed,
but from the phenomena attending its composition there can
be little doubt that it is a tersulphuret corresponding to colum-
bic acid; or a compound of

3 atoms sulphur	.	.	6
1 atom columbium	.	.	22·75

28·75

VIII. We are still ignorant of the compounds which colum-
bium may be capable of forming with selenium, tellurium,
arsenic, antimony, chromium, molybdenum, and tungsten.

As it always occurs native united to iron and manganese, it
is obvious that it must have a strong affinity for these metals.
Accordingly, when these compounds are heated with charcoal
the metals are reduced, and a triple alloy of columbium, iron,
and manganese, obtained.   When this alloy is digested in
muriatic acid, the iron and manganese are dissolved, and the
columbium remains.   This method might be employed for
obtained metallic columbium.

SECTION XVII.—OF TITANIUM.

In the valley of Menachan, in Cornwall, there is found a
black sand, bearing a strong resemblance to gunpowder.   It
was examined in 1791 by Mr. Gregor, who found it composed
almost entirely of iron and the oxide of a new metal, to which
he gave the name of *menachine*.†   He attempted in vain to
reduce this oxide to the metallic state; but his experiments were
sufficient to demonstrate the metallic nature of the substance,
and to show that it contained a metal till then absolutely
unknown.   This curious and ingenious analysis seems to have
excited but little attention, since nobody thought of repeating
it, or of verifying the conclusions of Mr. Gregor.

But in 1795 Klaproth published the analysis of a brownish-
red mineral, known to mineralogists by the name of *red shorl*.
He found it entirely composed of the oxide of a peculiar metal,
to which he gave the name of *titanium*.‡   He failed indeed in
his attempts to reduce this oxide; but his experiments left no
doubt of its metallic nature.   On examining in 1797 the black
mineral analyzed by Mr. Gregor, he found it a compound of

* Kongl. Vet. Acad. Handl. 1824, p. 287.
† Jour. de Phys. xxxix. 72, and 152.   ‡ Beitrage, i. 233.

the oxides of iron and titanium.*   Consequently the analysis of Mr. Gregor was accurate, and his *menachine* is the same with *titanium*, of which he was undoubtedly the original discoverer.   The term *titanium* has been preferred by chemists, on account of the great celebrity'and authority of the illustrious philosopher who imposed it.   Klaproth's experiments were repeated, confirmed, and extended by Vauquelin and Hecht in 1796, who succeeded in reducing a very minute portion of the oxide of titanium to the metallic state.†   They were repeated also and confirmed by Lowitz of Petersburgh in 1798.‡   Lampadius made a set of experiments on it in 1803,§ and a new set of experiments on it, by Laugier, was published in 1814.|| More lately numerous important experiments upon its combinations have been made by M. H. Rose ;¶ its chlorides have been examined by Mr. George** and M. Dumas :†† and Dr. Wollaston has described the properties of titanium in the metallic state.‡‡

Metallic titanium crystallized in small cubes is observed occasionally in the slag of the hearth, in the great iron smelting furnaces.   Specimens of these crystals were examined by Dr. Wollaston from Marthyr Tydvil in 1822, and found by him to be titanium.   They have been observed in various other furnaces of this country.   I have seen specimens of them from Muirkirk.   Mr. George obtained them from Low Moor Iron-works, near Bradford in Yorkshire.   Dr. Wollaston mentions also the Pidding Iron-works near Alfreton in Derbyshire, and Pontypool in Monmouth.'   They have been seen also in the Clyde Iron-works, but not for many years.   Walchner observed them in the Iron-works in Baden,§§ and doubtless they have been found in other places.   The metal may be obtained also by mixing titanic acid with charcoal powder, putting the mixture into a Hessian crucible, covering it with pounded glass, and then exposing the crucible, well covered, to the most violent heat that can be raised.   But this process is difficult, and succeeded only imperfectly with Laugier, while it has failed in the hands of every other person.

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* Beitrage, ii. 226.   † Jour. de Min. No. xv. 10.
‡ Crell's Annals, 1799, i. 183.   § Nicholson's Journal, vi. 62.
|| Ann. de Chim. lxxxix. 306.
¶ Kongl. Vet. Acad. Handl. 1821, p. 231.   Poggendorf's Annalen der Physik. iii. 163, xii. 479, and xv. 145.
** Annals of Philosophy (2d series), ix. 18.
†† Ann. de Chim. et de Phys. xxxiii. 386.
‡‡ Phil. Trans. 1823, pp. 17, 400.   §§ Schweigger's Jahrbuch, xi. 80.

I. Native metallic titanium has a copper-red colour, and a great deal of brilliancy. It is crystallized in cubes, in which Mr. W. Philips detected a cleavage parallel to the faces of the cube. It is hard enough to scratch rock crystal, and has a specific gravity of 5·3. These cubes affect a magnet very slightly, in consequence of a very small quantity of iron with which they are contaminated. They conduct electricity perfectly well.

These cubes are not acted on by nitric, muriatic, or sulphuric acid; nor is aqua regia capable of dissolving them. They are infusible before the blowpipe. When heated they are oxidized on the surface. When heated with nitre they are rapidly oxidized; but to oxidize them completely we must heat them with a mixture of borax and nitre. I find also that they are rapidly oxidized when heated with caustic potash.

H. Rose has discovered an unexpected process by which metallic titanium may be obtained. Anhydrous chloride of titanium is put into a proper apparatus, and a current of ammoniacal gas is made to pass into it till it is saturated. The matter is now heated till it sublimes. One part of the salt sublimes, while another part is decomposed. Muriatic acid and azote are disengaged, and metallic titanium remains. In this state of fine powder, if titanium be heated in air, it takes fire. It dissolves also in aqua regia. It has in these respects a close resemblance to silicon, which, when strongly heated, loses its combustibility in air, and its solubility in fluoric acid.

II. We are acquainted with two different combinations of titanium and oxygen; the one is black, or bluish, or purplish and is incapable of combining either with acids or bases; the other possesses acid characters, and has received the name of titanic acid. *Oxides.*

1. Oxide of titanium may be obtained by enclosing titanic acid in a charcoal crucible, and exposing it to a very violent heat in a covered crucible. We obtain a mass coated externally by a thin red crust of metallic titanium. Within is oxide of titanium in the state of a black powder. I find also that it may be formed by heating metallic titanium in fine powder in a platinum crucible along with caustic potash. In that case it has a bluish green colour, probably because the titanium which I employed was not free from iron. *Protoxide.*

Oxide of titanium, when prepared from titanic acid, is insoluble in all the acids. When heated it absorbs oxygen very slowly. Indeed it is with great difficulty converted into titanic acid by heating it along with nitre. Before the blow-

pipe it dissolves in biphosphate of soda, and forms a very dark red glass.   Oxide of titanium is formed when a plate of zinc or iron is put into a solution of titanic acid in muriatic acid. The liquid gradually assumes a purple colour, and the oxide of titanium at last falls down, having the same shade of colour. But when thus obtained its tendency to absorb oxygen is so great that it cannot be filtered or dried without being converted into titanic acid.

I think it probable that the *anatase* of mineralogists, a beautiful *blue* or *brown* mineral, crystallized in elongated octahedrons, and having a specific gravity of 3·826, is composed of oxide of titanium.   But this mineral is so scarce that chemists have not been able to procure enough of it for a chemical analysis.

Titanic acid. 2. Titanic acid occurs native crystallized in right four-sided prisms, and is known by the names of *titanite* or *rutile*.   Its colour is usually reddish-brown, and it has a specific gravity of 4·249.   It probably owes its colour to the presence of a little oxides of iron and manganese, from which it has never been met with quite free.   Nor was it known in a state of purity till M. H. Rose contrived the following process for purifying it.

Preparation.   The cheapest substance to employ is titaniate of iron or titanious iron ore.   Reduce this ore to powder, and expose it to a white heat in a porcelain tube, while a current of dry sulphuretted hydrogen gas ·passes through it.   By this process the oxide of iron is converted into sulphuret, while the titanic acid undergoes no change.   Allow the tube to cool, and digest the ore thus altered in concentrated muriatic acid.   Much sulphuretted hydrogen is given off, and sulphur is deposited, which being mixed with the titanic acid gives it a gray colour.   Wash the acid, dry it, and expose it to a red heat to drive off the sulphur.   Titanic acid obtained in this way still retains oxide of iron, and becomes red when calcined.   The best way of proceeding therefore is not to continue the current of sulphuretted hydrogen gas as long as water continues to be evolved, but to stop when the quantity of water disengaged begins to diminish.   The titanic acid obtained by digesting the residue in muriatic acid, is to be put again into the porcelain tube, heated to whiteness, and a current of sulphuretted hydrogen passed over it.   After this if it be digested in concentrated muriatic acid, washed, dried, and heated, it will be quite white and pure.*

* Poggendorf's Annalen der Physik. xii. 479.

We may obtain titanic acid from *rutile* (which is an impure titanic acid, or rather titaniate of iron), by reducing the mineral to an impalpable powder, and fusing it with thrice its weight of carbonate of soda.   The fused mass is washed with water, which carries off the excess of alkali, and leaves the supertitaniate of soda.   Let this supertitaniate be washed on a filter as long as the water passes through clear.   Then dissolve it in concentrated muriatic acid.   Dilute the solution with water and boil it.   The greatest part of the titanic acid falls down, while the oxides of iron and manganese remain in solution. And the remainder of the titanic acid may be obtained by driving off the excess of muriatic acid from the liquid.   The titanic acid thus obtained must be washed with water acidulated with muriatic acid.   It still retains oxides of iron and manganese, which may be partly removed by reiterated boiling in muriatic acid, and completely by digesting it in hydrosulphuret of ammonia, as was first suggested by Rose.   This hydrosulphuret dissolves the oxide of tin which is sometimes present, and it converts the oxides of iron and manganese into sulphurets, which are easily removed by muriatic acid in the way above described.

Titanic acid thus obtained is a white tasteless powder. Properties. When heated it becomes yellowish, but resumes its white colour when again cold.   It does not melt at a high temperature.   It reddens litmus paper even after having been exposed to a red heat.   But after that process it becomes quite insoluble in acids, as was first observed by Klaproth.   It may have its solubility restored by fusing it with carbonate of soda, or by digesting it in concentrated sulphuric acid in a temperature sufficiently high to drive off by degrees the excess of sulphuric acid, or we may mix it with charcoal powder, and pass a current of dry chlorine gas through it while heated to redness.   Chloride of titanium is formed, which may be dissolved in water.   The titanic acid may be precipitated by ammonia from these solutions.   In this state it is white, gelatinous, very soluble in acids, and soluble also partially in the alkaline carbonates, without disengaging the carbonic acid.   To obtain a complete solution of this acid in the alkaline carbonates, we must let fall a solution of a titaniate, drop by drop, into the alkaline solution; agitating after every addition, and taking care to add no more till the preceding portion be dissolved. Titanic acid is precipitated from its solution in carbonate of ammonia by long boiling.   To throw it down from car-

bonates of potash or soda, we must add sal ammoniac and then boil.

Rose has shown that titanic acid is isamorphous with peroxide of tin. It is capable of existing in two distinct states. It is in one of these states where it is precipitated from an acid solution by potash. In that state it contains water, and dissolves readily in acids. When heated it loses its water, glows, and is converted into the other state in which it is perfectly insoluble in all acids. When dilute solutions of muriate or sulphate of titanium are long boiled, the titanic acid is thrown down in the second state, and is completely insoluble in water. In this second state it has a curious property, first noticed by Klaproth. If we throw it on a filter and wash it, the water passes off clear as long as it holds any salt in solution. But as soon as the titanic acid is pure, or nearly so, it mixes with the water, and forms a kind of milk, which passes through the filter. We cannot therefore wash titanic acid with pure water; we must employ water holding some sal ammoniac in solution.

Resembles zirconia.   The characters of titanic acid and zirconia resemble each other so closely that the one is often mistaken for the other. They may, however, be easily distinguished by the blowpipe. Titanic acid, when fused with borax or biphosphate of soda, in the exterior flame gives a yellow or colourless glass, which in the interior flame becomes deep purple, or even brown or black, if the quantity of titanic acid be considerable. When titanic acid and zirconia occur together in the same mineral, we do not possess the means of separating them from each other. Such minerals in the present state of chemical knowledge cannot be analyzed.

Atomic weight.   To determine the quantity of oxygen in titanic acid I converted 1·37 grain of metallic titanium into titanic acid, by heating it with a mixture of nitre and caustic potash in a green glass retort. The weight of the titanic acid formed was 2·085 grains. Hence titanic acid is a compound of

| Titanium | . | . | 1·37 or 3·83 |
| Oxygen | . | . | 0·715 or 2 |

This experiment (supposing titanic acid to contain 2 atoms oxygen) makes the weight of the atom of titanium 3·83.* There are two circumstances which render the result thus obtained not perfectly satisfactory. The first is, that the titanium employed was not quite free from every trace of iron, and the second was the smallness of the scale on which the

* First Principles, ii. 88.

experiment was made. A very trifling error in weighing
would occasion a material one in the result.

M. Rose has lately made a new set of experiments to deter-
mine this point. He decomposed chloride of titanium by mix-
ing it with water. He then precipitated the titanic acid formed
by ammonia, and the chlorine was afterwards thrown down by
nitrate of silver. Four different experiments were made, the
mean of which gives from 9·838 parts of chloride, 4·23 parts
of titanic acid, and 29·696 parts of chloride of silver = 7·322
parts of chlorine. It is obvious that 100 parts of chloride of
titanium by this treatment would have yielded

Titanic acid	. •.	42·996
Chlorine	. .	74·42 .

117·416

There is an excess of 17·416 parts. The reason of this excess
is, that the titanium in the chloride was in the metallic state,
while in the analysis it was in the state of titanic acid. Hence
this excess must represent the oxygen contained in 42·996
parts of titanic acid. Therefore if we can confide in these
experiments of Rose, titanic acid is a compound of

Titanium	. .	25·58 or 100
Oxygen	. .	17·416 68

42·996

But 68 represents two atoms of oxygen. Hence the atom of
oxygen is to that of titanium as 34 to 100, or as 1 to 2·94.
This considerably exceeds the quantity of oxygen which com-
bined with titanium in my experiment, when I converted it
into titanic acid.*

A set of experiments was also made by Dumas to determine
the same point. His method was to determine the specific
gravity of chloride of titanium vapour. He found it 6·836.
He then considered this vapour as a compound of two volumes
chlorine gas and 1 volume of titanium vapour condensed into
1 volume. Now the weight of two volumes of chlorine gas is
5. If we subtract this from 6·836, we have 1·836 for the
weight of a volume of titanium vapour. If we divide the
specific gravity of titanium vapour by 5·5555, the quotient will
be the atomic weight of titanium. But $\dfrac{1·836}{·5555} = 3·3.$†

There is still another analysis of chloride of titanium by

* Poggendorf's Annalen, xv. 145.
† Ann. de Chim. et de Phys. xxxiii. 388.

Mr. George. He dissolved a quantity of bichloride of titanium in water; and after one half of the chlorine was driven off, he divided the solution into two equal portions. From the one he threw down the titanic acid by potash, which weighed 7 grains, and from the other the chlorine, by means of nitrate of silver. The chloride of silver weighed 15 grains = 3·69 grains of chlorine. Hence the bichloride of titanium (analogous to titanic acid) must, by this analysis, have been a compound of

$$7 \quad \text{titanium} — x \text{ oxygen,}$$
$$7\cdot38 \text{ chlorine.}$$

But 7·38 represents 2 atoms of chlorine; and if we divide it by 4·5, it will give us the quantity of oxygen contained in 7 grains of titanic acid. $\frac{7\cdot38}{4\cdot5} = 1\cdot64.$ Hence titanic acid is a compound of

Titanium	. .	5·36 or 100
Oxygen	. .	1·64 or 30·6.[*]

This would make the atom of oxygen to that of titanium at 15 8 to 100, as 1 to 6·52.[†]

Thus we have four determinations of the atomic weight of titanium founded upon four different sets of experiments; these are as follows:

Thomson	. .	3·83
Rose	. .	2·94
Dumas	. .	3·3
George	. .	6·52

I do not think that we can put full confidence in the determination of Mr. George, because we have no evidence that one half of the chlorine was dissipated when the chloride was dissolved in water. It may have been so; but we have not sufficient evidence of the fact. I consider my own experiment as the simplest and easiest of all, and would confide in it in preference to the rest, had it been made upon a larger scale. I think Rose's mode of experimenting susceptible of accuracy. But the want of coincidence between his results and those of Dumas, whose mode of experimenting was also very simple, prevents us from putting complete confidence in either. Were we to take a mean of the results of Rose, Dumas, and my own,

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[*] Annals of Philosophy (2d series), ix. 20.

[†] I think it probable that the chlorine driven off when the chloride was dissolved in water, was merely the excess which the chloride usually contains at first. If so, the chlorine obtained by Mr. George represents two atoms, and the atom of titanium comes out by his experiments, 3·26, which I believe to be very near the truth.

we would get 3·356 as the atomic weight. It is evident that
farther researches are still necessary. Meanwhile 3·25, which
lies between the numbers of Rose and Dumas, has a consider-
able chance of being near the truth. I am therefore disposed
to adopt it. My old number 4 was founded on the analysis of
menachanite in my laboratory; and if we could confide in the
analysis of the different ores of titanium hitherto made, there
would be a strong probability that the atomic weight of titanic
acid is 6. But as titanic acid, like other weak acids, unites
with bases in a great variety of proportions, less confidence can
be put in the results of such analyses than when an acid unites
only in one or two proportions.

III. Chloride of titanium appears to have been discovered
by Mr. George in 1824, Dumas formed it in 1826, and Rose
in 1828. Nearly the same method was employed by all the
experimenters. George employed metallic titanium; but
Dumas and Rose used a mixture of titanic acid and charcoal.
The titanium or mixture of titanic acid and charcoal was put
into a glass or porcelain tube, heated to redness, and a current
of dry chlorine gas passed over it. In the receiver attached to
the tube, a liquid gradually condensed, which is the chloride
in question. When first obtained it contains an excess of
chlorine, which gives it a strong odour of that gas and a yellow
colour. But it is easily purified by shaking it with small
quantities of mercury, and distilling it two or three times from
a small retort in which a little mercury has been put. It is
then perfectly transparent and colourless, does not act upon
mercury, and when dissolved in water is converted into mu-
riatic acid and titanic acid, without the evolution of any chlorine
gas.* It is heavier than water, and it boils, according to
Dumas, when heated to the temperature of 275°. The specific
gravity of the vapour of this liquid was determined by Dumas
to be 6·836. If we suppose it a compound of two volumes of
chlorine and 1 volume of titanium vapour condensed into 1
volume, and if the atomic weight of titanium be 3·25, then the
specific gravity of its vapour will be 6·8055. For

$$2 \text{ volumes chlorine} = 5$$
$$3\text{·}25 \times 0\text{·}5555 \quad = 1\text{·}8055$$
_____
$$6\text{·}8055 = \text{specific gravity of the}$$

_____

* We see from this that the chlorine evolved in Mr. George's experiment
was foreign, and that two atoms of chlorine actually remained in solution
in the state of muriatic acid.

vapour.　Now this comes sufficiently near the specific gravity, as determined by Dumas, to make it not unlikely to be the true gravity; but new experiments are still requisite to decide this difficult point.

As chloride of titanium, when dissolved in water, is resolved into muriatic acid and titanic acid, there can be no doubt that it is a bichloride, and its constituents must be

2 atoms chlorine	.	.	9
1 atom titanium	.	.	3·25
			12·25

IV. No attempts have hitherto been made to combine titanium with bromine or iodine.

V. When titanic acid, fluor spar, and sulphuric acid, are mixed together in a leaden retort, a yellow coloured liquid is gradually obtained, which water immediately converts into fluoric acid and titanic acid.*　This is probably a fluoride of titanium.

VI. Nothing is known about the combinations which titanium may be capable of forming with hydrogen, azote, carbon, boron, and silicon.

Phosphuret.　VII. Chenevix formed the phosphuret of titanium by the following process: He put a mixture of charcoal, phosphate of titanium (phosphoric acid combined with titanic acid), and a little borax, into a double crucible, well luted, and exposed it to the heat of a forge.　A gentle heat was first applied, which was gradually raised for three quarters of an hour, and maintained for half an hour as high as possible.　The phosphuret of titanium was found in the crucible in the form of a metallic button.　It is of a pale-white colour, brittle, and granular; and does not melt before the blow-pipe.†

Sulphuret.　VIII. Sulphuret of titanium was first formed by Rose.　His method was to heat titanic acid to whiteness in a porcelain tube, and then to cause the vapours of bisulphuret of carbon to pass slowly over it.　Carbonic oxide is formed, and the sulphuret of titanium remains in the state of green grains, which, when rubbed, acquire the metallic lustre and a deep yellow colour.　These grains are soft and easily spread upon the skin like talc, communicating a metallic lustre.　When heated in the open air they are easily converted into titanic acid.

* Unverdorben as quoted by L. Gmelin; Handbuch der theor. chemie, i. 772.

† Nicholson's Jour. v. 134.

It dissolves with difficulty in the acids. When digested in muriatic acid, sulphuretted hydrogen is evolved. When boiled in aqua regia, the sulphur is acidified, and most of the titanic acid formed remains undissolved. But if we make aqua regia act on it cold, the greatest part of the titanic acid is dissolved. Caustic potash decomposes it, supertitaniate of potash remains, and sulphuret of potassium is dissolved. It is not soluble in the alkaline hydrosulphurets.

• This sulphuret contains, according to Rose, two atoms sulphur, and is composed of

Titanium	•	.	43
Sulphur	.	.	57
			100

These numbers (obviously hypothetic) would make the atomic weight of titanium 3·017.*

IX. Nothing is known respecting the combinations which titanium may be able to form with selenium, tellurium, arsenic, antimony, chromium, molybdenum, tungsten, and columbium. Vauquelin and Hecht attempted to combine it with silver, copper, lead, and arsenic, but without success. But they combined it with iron, and formed an alloy of a gray colour, interspersed with yellow-coloured brilliant particles. Dr. Wollaston tried in vain to combine it with tin, lead, silver, and copper. It would appear from these trials that the affinity of this metal, for other metals is in general weak.

SUCH are the properties of the acidifiable bases, so far as we are acquainted with them. The attentive reader will perceive that several of them are distinguished by their peculiar properties from all the rest, and stand as it were insulated; while others possess similar properties, and therefore constitute so many particular groups. Hydrogen and azote differ essentially from all the rest. They agree in being gaseous; but they differ so much in almost every other property that they cannot be grouped together.

Carbon, *boron*, and *silicon*, possess analogous properties. They are black, or very dark coloured powders, quite fixed, and incapable of fusion. The acids which they form with oxygen are not powerful, and are capable in consequence of uniting with bases in various proportions.

Sulphur, *selenium*, and *tellurium*, are also analogous bodies.

* Kongl. Vet. Acad. Handl. 1821, p. 253.

They combine with hydrogen, and form with it a gas capable of being absorbed by water, possessed of acid properties, and composed of a volume of hydrogen united to a volume of the vapours of the respective substances condensed into one volume. The acids of sulphur and selenium resemble each other in their composition; sulphurous and selenious acids containing two atoms of oxygen, while sulphuric and selenic acids contain each three atoms of oxygen. Similar acids of tellurium have not yet been discovered.

Phosphorus, arsenic, and *antimony,* bear a close resemblance to each other. They are isomorphous substances; the proportions of oxygen with which they combine are respectively similar, $1\frac{1}{2}$, 2, $2\frac{1}{2}$. They unite to hydrogen, but the gases which they form with it do not possess the properties of acids, nor are they absorbed in a notable proportion by water. They consist of a volume and a half of hydrogen gas united to a volume of the vapour of phosphorus or arsenic, and condensed into one volume. Antimonietted hydrogen gas has not yet been discovered.

Chromium and *uranium* approach each other in their colouring properties; but they deviate in other respects from each other. Chromic acid contains $2\frac{1}{2}$ atoms oxygen, while uranic acid contains $1\frac{1}{2}$ or 2 atoms; most probably the latter.

Molybdenum and *tungsten, columbium* and *titanium,* form two other groups not so closely connected. But the investigation of these four bodies is still too incomplete to enable us to draw analogies.

CHAP. III.

OF SIMPLE ALKALIFIABLE BASES.

THE simple alkalifiable bases at present known are the following:

1. Potassium,	8. Aluminum,	15. Manganese,
2. Sodium,	9. Glucinum,	16. Nickel,
3. Lithium,	10. Yttrium,	17. Cobalt,
4. Barium,	11. Cerium,	18. Zinc,
5. Strontium,	12. Zirconium,	19. Cadmium,
6. Calcium,	13. Thorium,	20. Lead,
7. Magnesium,	14. Iron,	21. Tin,

22. Bismuth,	26. Gold,	29. Rhodium,
23. Copper,	27. Platinum,	30. Iridium,
24. Mercury,	28. Palladium,	31. Osmium.
25. Silver,		

These bodies for the convenience of the learner may be sub-divided into five families, the individuals belonging to each of which possess a great many characters in common. These are as follows :

First family. Alkaline bases.

This family comprehends the 7 following bodies.

1. Potassium,	4. Barium,	6. Calcium,
2. Sodium,	5. Strontium,	7. Magnesium.
3. Lithium,		

The combinations of these bodies with oxygen are soluble in water, change vegetable blue colours into green, and neutralize acids with great energy. These are the characters which distinguished the alkalies, as they were understood by the older chemists.

Second family. Earthy bases.

This family comprehends the 6 following bodies.

| 1. Aluminum, | 3. Yttrium, | 5. Zirconium, |
| 2. Glucinum, | 4. Cerium, | 6. Thorium. |

The combinations of these bodies with oxygen constitute white tasteless powders, insoluble in water, incapable of producing any alteration on vegetable blues, and of completely depriving acids of the power to redden litmus paper; and capable of enduring a high temperature without undergoing any change. These are the characters by which the *earths* of the older chemists were recognised.

Third family. Difficultly fusible bases.

The third family comprehends the 4 following bodies.

| 1. Iron, | 3. Nickel, |
| 2. Manganese, | 4. Cobalt. |

The combinations of these bodies with oxygen cannot be reduced to the metallic state by heat alone; but they readily dissolve in acids, and from this solution they cannot be precipitated by introducing into it a rod of zinc, as is the case with the bases belonging to the fourth family. Each of them unites to oxygen in two proportions. The first is a compound

of 1 atom of base with 1 atom of oxygen ; and the second of 1 atom of base with $1\frac{1}{2}$ atom of oxygen.* All the bases belonging to this family require a violent heat to melt them. They are all magnetic except manganese.

Fourth family. Easily fusible bases.

This family comprehends the eight following bodies.

1. Zinc,	4. Tin,	7. Mercury,
2. Cadmium,	5. Bismuth,	8. Silver.
3. Lead,	6. Copper,	

These bodies are all malleable metals except bismuth, which is not very brittle. They all melt at a comparatively low heat. Indeed if we except zinc and silver, which require a red heat, and copper which requires a white heat, they all melt at a temperature below redness. When a rod of zinc or iron is put into the solution of any of these bodies in an acid, except zinc, it is precipitated in the metallic state, while the zinc or the iron is dissolved in its place. They combine either with one proportion or with two proportions only of oxygen. Their oxides (those of tin excepted), have the property of neutralizing acids, and of forming salts capable of crystallizing.

Fifth family. Noble metals.

This family comprehends the six following bodies.

1. Gold,	3. Palladium,	5. Iridium,
2. Platinum,	4. Rhodium,	6. Osmium.

These bodies require, all of them, a strong heat to fuse them. They are all insoluble in nitric acid, and their oxides are reducible to the metallic state by the application of heat alone. These oxides, in general, exhibit but little tendency to combine either with acids or bases, or to form salts. The consequence is, that but few saline combinations into which they enter are known.

All the bodies belonging to these five families are metals ; and with the exception of nine, they comprehend all the metallic bodies at present known. None of the *supporters* are metals. The first eight of the acidifiable bases are not metallic, but the last nine are.

The name *metal* was formerly applied to certain substances distinguished by a peculiar lustre, called the *metallic lustre*, capable of being extended under the hammer, and of being

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* Manganese forms at least four different oxides, if not five.

drawn out into wire, or *malleable* and *ductile*, opaque, and possessed of a much higher specific gravity than any other substances; capable of being melted by heat, and conductors of electricity. At first only 7 metals were known, namely gold, silver, mercury, copper, iron, lead, and tin; which possessed all these characters. By degrees other substances were discovered, possessed of the metallic lustre; but neither malleable nor ductile; as for example antimony, arsenic, bismuth, tellurium. These were sometimes distinguished by the epithet *semimetal* or *imperfect metal.* By degrees the number of these new bodies far exceeded the old ones. Some of them cannot be fused by the most violent heat that we can apply; many are neither ductile nor malleable, some are lighter than water, and gold can be hammered out so thin that it allows the light to pass through it. Thus all the characters by which the metals were distinguished, have failed in the universality of their application except two; namely the *metallic lustre* and the property of *conducting electricity.* But this last property is not peculiar to the metals. Water possesses it, as does charcoal, and various bodies into which metallic particles enter as constituents. Nothing, therefore, remains to characterize the metals but the metallic lustre; much too vague a character to be the foundation of a class.

Under these circumstances I have thought it better to abandon the class of metals altogether, and to arrange the simple bodies into classes founded upon properties much more characteristic and important than metallic lustre.

FIRST FAMILY. ALKALINE BASES.

The bodies belonging to this family, which are 7 in number, will be treated of in the seven following sections.

SECTION I.—OF POTASSIUM.

If a sufficient quantity of wood be burnt to ashes, and these ashes be afterwards washed repeatedly with water till it comes off free from any taste, and if this liquid be filtrated and evaporated to dryness, the substance which remains behind is *potash;* not, however, in a state of purity, for it is contaminated with several other substances, but sufficiently pure to exhibit many of its properties. In this state it occurs in commerce under the name of *potash.* When heated to redness, many of its impurities are burnt off: it becomes much whiter than

before, and is then known in commerce by the name of *pearl-ash*. Still, however, it is contaminated with many foreign bodies, and is itself combined with carbonic acid gas, which blunts all its properties. It may be obtained perfectly pure by the following process :

1. Mix it with twice its weight of quicklime, and ten times its weight of pure water : boil the mixture for some hours in a clean iron vessel, or allow it to remain for 48 hours in a close glass vessel, shaking it occasionally. Then pass it through a filter. Boil the liquid obtained in a silver vessel very rapidly, till it is so much concentrated, as to assume when cold the consistence of honey. Then pour upon it a quantity of alcohol equal in weight to one-third of the pearl-ash employed. Shake the mixture, put it on the fire, let it boil for a minute or two, then pour it into a glass vessel, and cork it up. The solution gradually separates itself into two strata : the lowest consists of the impurities, partly dissolved in water and partly in a solid state ; the uppermost consists of the pure potash dissolved in alcohol, and is of a reddish-brown colour. Decant this alcohol solution into a silver basin, and evaporate it rapidly till a crust forms on the surface, and the liquid below acquires such consistence as to become solid on cooling. Then pour the solution into a porcelain vessel. When cold, it concretes into a white substance, which is pure potash. It must be broken to pieces, and put into an air-tight phial.

For this process we are indebted to Berthollet.* The following, which was first proposed by Lowitz of Petersburgh, is less expensive. The potash of commerce and quicklime are to be boiled together, as above described. The filtered liquor is then to be evaporated till a thick pellicle appears on its surface, and afterwards allowed to cool : and all the crystals which have formed are to be separated, for they consist of foreign salts. The evaporation is then to be continued in an iron pot ; and, during the process, the pellicle which forms on the surface is to be carefully taken off with an iron skimmer. When no more pellicle appears, and when the matter ceases to boil, it is to be taken off the fire, and must be constantly agitated with an iron spatula while cooling. It is then to be dissolved in double its own weight of water. This solution is to be filtered and evaporated in a glass retort† till it begins to deposite

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* Jour. de Phys. xxviii. 401.

† Dr. Kennedy observes, very justly, that a glass retort ought not to be employed, because potash in this state dissolves glass. Edin. Trans. v. 97.

regular crystals. If the mass consolidates ever so little by cooling, a small quantity of water is to be added, and it must be heated again. When a sufficient number of crystals have been formed, the liquor which swims over them, and which has assumed a very brown colour, must be decanted off, and kept in a well-closed bottle till the brown matter has subsided, and then it may be evaporated as before, and more crystals obtained.*

A still simpler method was employed by Klaproth. He boiled equal parts of salts of tartar (carbonate of potash prepared from tartar), and Carrara marble or oyster shells, burnt to lime, with a sufficient quantity of water, in a polished iron kettle. The ley was then strained through clean linen, and though still turbid, was reduced by boiling, till it contained about one half its weight of potash. It was then passed a second time through a linen cloth, and set by in a glass bottle. After some days, when the ley had become clear of itself, it was decanted off from the sediment into another bottle.†

When the processes above described are employed, it is quite possible for the potash obtained to be mixed with soda. The following process of Mr. Donovan of Dublin will put it in our power to obtain potash in a state of purity. Dissolve the *bicarbonate of potash* of commerce to saturation in water, of the temperature of 100°. Filter the solution and place it in a flat dish before the fire. In a few hours a crop of crystals of pure bicarbonate is obtained. Wash them with a little water, and dry them on blotting paper. Dissolve these crystals in water, and mix them with their own weight of slacked lime. Boil the mixture for 15 minutes, and then filter.‡

If we wish to render the potash caustic we must boil the solution of it with at least its own weight of quicklime. The best method is to slack the lime, and then to add as much water as will bring it to a half liquid state. The solution of carbonate of potash should be made to boil in a clean iron or silver vessel; then a spoonful of the half liquid lime should be added, and the liquid boiled for a few minutes. After this an additional spoonful is to be added, and the boiling continued. By this gradual addition of the lime it is converted into carbonate, and falls to the bottom in a gritty state, so that the caustic ley is easily separated from it. When we suppose that we have added enough of lime, we may test the liquid by taking out a little and mixing it with its own bulk of lime water. If the

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* Nicholson's Journal, i. 164.   † Klaproth's Beitrage, i. Preface, p. 10.
‡ Dublin Philosophical Journal, i. 48.

mixture remain transparent, the whole carbonic acid has been removed.

When the liquid has been rendered perfectly caustic, besides potash, it always contains a little lime in solution; which may be removed by cautiously dropping a solution of carbonate of potash, and agitating as long as a precipitate falls.

Even the potash obtained by means of alcohol, is not absolutely pure. Besides a good deal of water from which we cannot free it, the alcohol dissolves also chloride of potassium, which is always present in the potash of commerce, and some carbonate of potash is formed at the expense of the alcohol during the evaporation. When we take Mr. Donovan's method of employing bicarbonate of potash, the liquid will contain no other impurity than a little carbonate of potash, from which it would be difficult to free it; but it is of no importance, as far as regards almost all the purposes to which it is usually applied.

History.   That potash was known to the ancient Gauls and Germans cannot be doubted, as they were the inventors of soap, which, Pliny informs us, they composed of ashes and tallow. These ashes (for he mentions the ashes of the beech-tree particularly) were nothing else but potash; not, however, in a state of purity.* The κονια, too, mentioned by Aristophanes and Plato, appears to have been a ley made of the same kind of ashes. The alchymists were well acquainted with it; and it has been in every period very much employed in chemical researches. It may be said, however, with justice, that till Berthollet published his process in the year 1786, chemists had never examined potash in a state of complete purity.†

2. Potash is a brittle substance of a white colour, and a smell resembling that which is perceived during the slacking of quicklime. Its taste is remarkably acrid; and it is so exceedingly corrosive, that when applied to any part of the body, it destroys it almost instantaneously. On account of this property, it has been called *caustic*, and is often used by

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* Plinii, lib. xviii. c. 51.

† Potash was long distinguished by the name of *vegetable alkali*, because it is obtained from vegetables, and because it was long thought to be peculiar to the vegetable kingdom; but this is now known to be a mistake. It was called also *salt of tartar*, because it may be obtained by burning the salt called *tartar*. Mr. Kirwan has given it the name of *tartarin;* Klaproth, *kali;* and Dr. Black, *lixiva.* By most British chemists it is called *potash;* but this term, in common language, signifies the carbonate of potash, or the potash of commerce.

surgeons, under the name of the *potential cautery*, to open absces-
ses, and to destroy useless or hurtful excrescences. Its spe-
cific gravity in the state of hydrate is 2·1.*

3. When potash is perfectly dry it is a non-conductor of elec-
tricity, but it becomes a conductor when slightly moistened on
the surface, a degree of moisture which it acquires by being
exposed for a few seconds to the atmosphere. When pieces
of potash in this state are placed upon a disc of platinum
attached to the positive end of a powerful galvanic battery, and
a platinum wire from the negative extremity is made to touch
its upper surface, the potash is gradually decomposed, oxygen
gas separating at the extremity of the positive pole, while
globules of a white metal like mercury appear at the side in
contact with the platinum wire. A number of accurate experi-
ments demonstrated to Sir H. Davy that these globules were
the basis of potash, and that they were converted into potash by
absorbing oxygen. This brilliant discovery was made in the
year 1807.† To the metallic basis, thus discovered, Davy
gave the name of *potassium.*‡

Soon after Gay-Lussac and Thenard discovered that potas-
sium could be obtained in greater quantities by passing potash
through iron turnings, heated to whiteness in a gun-barrel
covered on the outside with clay to protect it from the action
of the fire.§ This difficult process was improved by Mr.
Smithson Tennant in 1814.‖

The potassium obtained by this process amounts to about
the fourth part of the weight of the hydrate of potash employed.
About two-thirds of the potash combine with the iron, forming
a compound of a peculiar nature, not hitherto examined. It
adheres strongly to the iron tube, and is scarcely soluble in
water.

Curaudau proposed another method of obtaining potassium.
He took the barrel of a pistol, shut up the touch-hole, and
covered it with a clay lute. He then introduced into it a
mixture of cream of tartar, previously heated to redness in a
crucible, and mixed afterwards with a little powdered charcoal
and oil. This tube he heated to whiteness in a forge till green
coloured vapours began to issue. Then bars of polished iron

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* Dalton.
† Davy has given a detailed account of it in Phil. Trans. 1808.
‡ The German and Swedish chemists call it *kalium*.
§ This process is described at length in Rech. Physico-chimiques, i. 74.
‖ Phil. Trans. 1814, p. 587.

were introduced into the barrel, till within a few lines of the incandescent mass, and instantly withdrawn. They were coated with small globules of potassium, which were detached, and kept under naphtha.*

This process of Curaudau yielded very little potassium. But about the year 1824, it was so much improved by M. Brunner, Professor of Chemistry at Berne, that it now furnishes by far the easiest and most economical method of procuring potassium.†

Preparation. The vessel which answers best for the process is a bottle of hammered iron; and Brunner recommends for it the iron bottles in which mercury is put when imported from the mercurial mines. If such a bottle is to be used, it ought, in the first place, to be exposed to a white heat to drive off all the mercury which may be attached to the inside of it. This bottle is to be filled with the black matter into which cream of tartar is converted by heating it to redness in a crucible. This black matter is a mixture of carbonate of potash and charcoal. To prevent it from melting when heated, it is proper to mix it intimately with a quantity of charcoal powder, weighing about $\frac{1}{14}$th of the cream of tartar employed. With this mixture the iron bottle is filled. It is then placed horizontally in a good wind furnace, being supported behind by a piece of fire-brick.
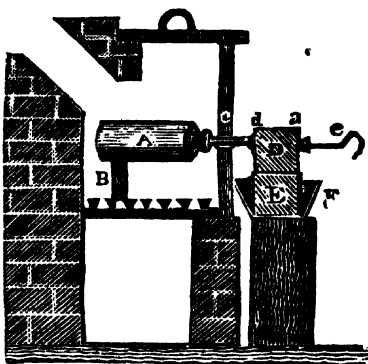
The figure in the margin represents a section of the furnace, with the iron bottle A, supported by the fire-brick B. To the mouth of the iron bottle a short iron tube C, (a piece of a gun barrel will answer,) is either to be fitted by means of a female screw in the mouth of the bottle, or simply by grinding. This tube must pass through a hole in a fire-brick, with which the mouth of the furnace is shut. It should be as short as possible, so as completely to clear the furnace. This tube is luted to a hole

* Ann. de Chim. lxvi. 97.

† Bibliotheque Universelle, xxii. 36.—Poggendorf's Annalen der Physik. iv. 23, where Brunner's process, as improved by Berzelius, is described by Wöhler; and in the same volume L. Gmelin (p. 31), gives an interesting account of the phenomena attending the process, and describes some new products, particularly *croconic acid.*

in the receiver D, which was con-
trived by Berzelius, and which I
shall endeavour to describe. It is
made of tinned copper, and con-
sists of two pieces. The upper
piece D is a thin parallelopiped,
ten inches long, five or six broad,
and $1\frac{1}{2}$ thick. It is shut at the
top and open at the bottom. To-
wards the side a, it is divided into
two parts by the diaphragm $b\,b$,
which goes within a third of the
bottom, and separates it com-
pletely, as far as it goes, into two
separate compartments. Towards the top of D there is a small
opening d, into which the end of the gun-barrel enters, and to
which it is luted air-tight, or what is better, the gun-barrel
should be fitted to it by grinding. Exactly opposite to it at a,
there is another opening fitted with a cork, through which an
iron wire $e\,e$ passes air-tight. It passes also through a cork
fitted into the diaphragm $b\,b$. The use of this iron wire is to
keep the gun-barrel tube from being filled up during the pro-
cess with a black matter which is volatilized into it.
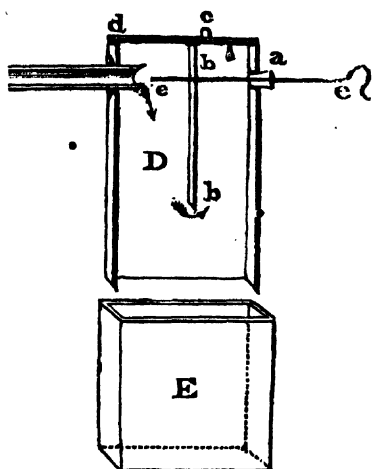
E is the other division of the receiver. It is a parallelo-
piped of tinned copper, similar to the upper half; open above
and shut below. D fits it exactly, so that it can be plunged
to the bottom of it. A few inches of naphtha are put into the
vessel E; then D is slipped into it, and the place between D
and E is well luted with fat lute, or putty, to prevent the air
from penetrating. The same precaution is taken with the
joining at d. Near the top of the vessel D, between the dia-
phragm and a, there is another small opening, to which a bent
glass tube is luted, which plunges into a vessel filled with
naphtha. The use of this tube is to allow the gases generated
to escape, without air having access to the inside of the receiver.

The iron bottle with its contents, and gun-barrel tube, being
put into the furnace, is heated to redness, and the heat raised
till green-coloured vapours begin to make their appearance,
which is a proof that the decomposition has begun. The re-
ceiver is then attached, and the process continued. As long as
gas issues from the bent tube, it is a proof that the process is
going on. If the issue stops, it is a proof that the gun-barrel
is stopt up. It must be cleared by the iron wire $e\,e$. This

iron wire for that purpose should terminate in a kind of cork-screw point. It should nòt be too thick. For in one of my processes I thought to secure the opening from the bottle through the gun-barrel by means of a round iron bar, terminating in a screw point. But very soon I found that all my force was insufficient to remove the obstruction, and was obliged in consequence to stop the process. I succeeded much better with an iron wire. But it is exceedingly difficult by any method whatever to prevent the gun-barrel from being choked up.

When no more gas issues, though the tube be open, the process is finished. If the operation has been successful, we find the potassium for the most part in globules at the bottom of the receiver E. It is always mixed with more or less of the black matter which obstructed the tube. When this black matter is distilled, it yields a good deal of potassium. We must beware of letting any water come in contact with it, for it burns, and even explodes violently, whenever we wet it. The greatest part of the potassium has been dissipated along with the gas. We obtain about 3 parts of potassium for every 100 parts of cream of tartar that we employ in the process.

The potassium thus obtained contains charcoal, from which it may be freed by distillation. I perform this in small bottle-glass retorts, which I fill with naphtha, and plunge their beaks into a receiver nearly filled with naphtha. The naphtha first passes over, and then the potassium, except a small quantity which cannot be separated from the charcoal, except by a heat greater than the retort can bear.

I have been thus particular in describing this process, because it is the most economical one hitherto contrived, and it will of consequence be hereafter followed for preparing this most important chemical agent.

The properties of potassium were ascertained with much industry and sagacity by Sir H. Davy.* They were likewise examined with much care by Gay-Lussac and Thenard, who corroborated the facts determined by Davy, and added some important ones of their own.†

Properties.   , Potassium is white, and it has the metallic lustre as completely as silver or mercury. At the temperature of 50° it is a soft and malleable solid. Its fluidity becomes perfect at $136\frac{1}{2}$°, and at 32° it is hard and brittle, and when broken in fragments

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* Phil. Trans. 1808, p. 1.   † Recherches Physico-chimiques, i. 107.

exhibits a crystalline structure. Nearly a red heat is required to convert it into vapour. Its specific gravity at 60° is 0·86507, so that it is lighter than water. It is an excellent conductor of electricity and of heat.

When potassium is exposed to the air, it absorbs oxygen, and is covered with a crust of potash in a few minutes. This crust absorbs water, which is rapidly decomposed, and in a short time the whole becomes a saturated solution of potash. When heated in oxygen gas to the temperature at which it begins to evaporate, it burns with a brilliant white light producing intense heat.

When thrown upon the surface of water it decomposes that liquid with rapidity, and the hydrogen gas evolved, carrying with it small particles of the metal, takes fire in the air, and communicating the combustion to the potassium, the whole burns with a kind of explosion, emitting a red light.

II. Potassium is generally considered as capable of uniting with three portions of oxygen; but I think it very doubtful whether the suboxide be any thing else than a mixture of potassium and potash. _Oxides._

1. The suboxide is formed when potassium is heated in a quantity of air not having enough of oxygen to convert it into potash; or by heating a mixture of 1 part potassium, and 1½ of hydrate of potash to a temperature not exceeding 570 degrees of Fahrenheit. While hot it has a red colour, but becomes gray on cooling. When heated to about 80°, it takes fire and burns brilliantly. At a temperature below redness, it is converted into peroxide of potassium; at a white heat it is decomposed into potassium which sublimes, and potash which remains. It has not been analyzed. But if it be a true suboxide, it is probably a compound of two atoms potassium and 1 atom oxygen. _Suboxide._

2. Potassium is converted into potash when put into water. That liquid is decomposed giving out hydrogen gas, while its oxygen unites to the potassium and converts it into potash. According to the experiments of Gay-Lussac and Thenard 34·177 grains of potassium when put into water, evolve 40·655 cubic inches of hydrogen gas at the temperature of 59°, and when the barometer stands at 29·351 inches.[*] Hence, under a pressure of 30 inches of mercury, the quantity of gas evolved would have been 39·776 cubic inches. According to this _Potash._

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[*] Recherches Physico-chimiques, i. 117.

experiment, 100 grains of potassium, when converted into potash in water, occasion the evolution of 116·38 cubic inches of hydrogen gas. Consequently the potassium must have united with a quantity of oxygen equivalent to 58·19 cubic inches. But 58·19 cubic inches weigh 20·137 grains. According to this experiment, potash is composed of

　　　　　　　Potassium　　.　　.　　100
　　　　　　　Oxygen　　　.　　.　　20·137

Berzelius took an amalgam of potassium, decomposed it by water, saturated the potash by muriatic acid, and then determined its quantity by weighing the salt which he had thus formed. The loss of weight of the amalgam gave him the quantity of potassium. This weight, subtracted from that of the potash, gave the quantity of oxygen with which it had combined. The result of his experiments gave him potash, composed of 100 potassium + 20·525 oxygen;* but which he afterwards corrected to the following numbers :†

　　　　　　　Potassium　　.　　.　　100
　　　　　　　Oxygen　　　.　　.　　20·409

Now the mean of these two sets of experiments gives us potash composed of

　　　　　　　Potassium　　.　　.　　100
　　　　　　　Oxygen　　　.　　.　　20·273

Hence, I think, we may without hesitation adopt the following as the true proportions in which the constituents of potash combine :

　　　　　　　Potassium　　.　　.　　100
　　　　　　　Oxygen　　　.　　.　　20

If we consider potash as a compound of one atom potassium and one atom oxygen, and nothing appears contrary to this supposition; then it follows that the weight of an atom of potassium is 5, and that of an atom of potash 6; 6 accordingly is the equivalent number according to which potash enters into all combinations.

Pure potash was first obtained by burning potassium and exposing the potash formed to a heat sufficient to drive off any surplus oxygen which it may have absorbed. Its colour is grayish-white, it melts at a red heat, and sublimes when the heat is raised a little higher. The fused mass is hard, breaks with a conchoidal fracture, and has a higher specific gravity than the hydrate of potash. It unites to water with much

* Ann. de Chim. lxxv. 245.　　　　　† Annals of Philosophy, iii. 360.

violence, and if only the requisite proportion of water has been employed, the heat evolved is sufficient to make the potash red-hot.

When potash is obtained by any of the processes described in the beginning of this section, it is in the state of a hydrate. If it be pure and exposed to a red heat, it fuses, and the matter thus obtained is a compound of

1 atom potash . .	6	or 100
1 atom water . .	1·125	or 18·75

7·125

The hydrate of potash has a very strong affinity for water. At the common temperature of the air, one part of water dissolves two parts of potash. The solution is transparent, very dense, and almost of the consistence of oil. It is in this state that potash is usually employed by chemists. When four parts of potash in powder and one of snow are mixed together, the mixture becomes liquid, and at the same time absorbs much heat. This mixture was employed by Lowitz to produce artificial cold. When the aqueous solution of potash is evaporated to a proper consistency, the potash crystallizes. The shape of its crystals is very different, according to the way in which they have been produced. When allowed to form spontaneously, they are octahedrons in groupes, and contain 0.43 of water, or they are composed of

Hydrate of potash.

1 atom potash . .	6
4 atoms water . .	4·5

10·5

These octahedral crystals therefore constitute a quaterhydrate of potash. When formed by evaporation on the fire, they assume the figure of very thin transparent blades of extraordinary magnitude, which, by an assemblage of lines crossing each other in prodigious numbers, present an aggregate of cells or cavities, commonly so very close, that the vessel may be inverted without losing one drop of the liquid which it contains.*

The following table by Mr. Dalton† exhibits the quantity of potash contained in 100 parts of solutions of potash in water, of different specific gravities:

* Nicholson's Journal, i. 164.
† Dalton's New System of Chemistry, Part ii. p. 476.

Sp. grav. of solution.	Potash per cent.	Sp. grav. of solution.	Potash per cent.	Sp. grav. of solution.	Potash per cent.
1·68	51·2	1·42	34·4	1·23	19·5
1·60	46·7	1·39	32·4	1·19	16·2
1·52	42·9	1·36	29·4	1·15	13·0
1·47	39·6	1·33	26·3	1·11	9·8
1·44	36·8	1·28	23·4	1·06	4·7

Potash is employed in medicine both externally and internally. It is proper on that account to mention that the caustic potash prepared for medical use in this country is seldom quite free from lead. I cannot account for this, except by supposing that the potash is prepared in leaden vessels—a very improper practice, because potash has the property of dissolving protoxide of lead with great facility.

Peroxide.

3. The peroxide of potassium was discovered in 1810, by Gay-Lussac and Thenard. It is formed by heating potassium in a glass jar filled with oxygen gas. A vivid combustion takes place, and a great deal of oxygen gas is absorbed. From the experiments of Gay-Lussac and Thenard, it appears that 100 grains of potassium, when thus burnt, are capable of absorbing 177 cubic inches of oxygen gas. Hence this peroxide is composed of

Potassium . . 100 or 5
Oxygen . . 61·25 or 3·06

So that it is a compound of 1 atom potassium and 3 atoms oxygen.

This peroxide is a solid body of a yellow colour. It fuses when exposed to a temperature higher than is requisite to fuse common caustic potash. On cooling, it crystallizes in plates. When put into water, it effervesces, and is reduced to the state of potash, giving out the excess of oxygen which it contained. When brought in contact with phosphorus, sulphur, or carbon, combustion takes place when the temperature is raised; these bodies are acidified, and the acids formed unite to the potash. When surrounded with hydrogen and heated, that gas is absorbed without the appearance of light, and much water is formed. In like manner, sulphurous acid, and protoxide of azote, are acidified when it is heated in them. Ammonia is decomposed, water being formed and azotic gas disengaged.[*]

When hydrate of potash is fused in an open silver crucible, the peroxide of potassium is frequently formed; the oxygen of the atmosphere being absorbed, and taking the place of the water. Hence it happens that hydrate of potash, after having

[*] Recherches Physico-chimiques, i. 128.

been fused by a violent heat, frequently dissolves in water with a lively effervescence, oxygen gas being disengaged.

III. Potassium combines readily with chlorine, and forms a compound called *chloride of potassium.*

Chloride.

When potassium is introduced into chlorine gas, it burns with a brilliant red flame, the chlorine is absorbed, and the whole is converted into a white saline mass. This substance is *chloride of potassium.* If potash be heated in chlorine gas its oxygen is disengaged, while the chlorine is absorbed and takes its place. It appears from this experiment, which was made by Davy, that at a red heat potassium has a stronger affinity for chlorine than it has for oxygen. This chloride is a compound of

1 atom chlorine	. .	4·5
1 atom potassium	. .	5
		——
		9·5

It possesses the characters of a salt. On that account, I shall reserve the description of it to the second volume of this work.

IV. Potassium combines very readily with bromine. Simple exposure to the vapour of bromine is sufficient to produce the combination. The cubic crystals obtained by saturating ether impregnated with bromine and evaporating, constitute bromide of potassium. Its taste is sharp. When heated it decrepitates, and melts at a red heat, without undergoing alteration. At a high temperature it is decomposed by chlorine; but iodine has no action on it. It is decomposed by sulphuric acid, which disengages vapours of hydrobromic acid and bromine. From the analysis of Balard, it is evidently composed of

Bromide.

1 atom bromine	. .	10
1 atom potassium	. .	5
		——
		15*

V. Potassium combines with iodine, and forms a compound which we shall call *iodide of potassium.*

When the vapour of iodine comes in contact with potassium the metal takes fire and burns with a violet coloured flame, while the iodine is absorbed. The compound melts, and is volatilized at a temperature below redness. On cooling it crystallizes, and assumes a pearly lustre. It dissolves readily in water, and the solution does not alter vegetable blues. This iodide is composed of

Iodide.

* Balard, Ann. de Chim. et de Phys. xxxii. 355.

1 atom iodine   .   .   15·75

1 atom potassium   .   .   5

It possesses also the characters of a salt, and will come under our view hereafter.

VI. When potassium is heated in hydrogen gas a portion of it is volatilized, and remains mixed with the gas. The hydrogen, in consequence, acquires the power of burning spontaneously when mixed with common air or oxygen gas. But if the gas be kept it speedily deposits the potassium, and is reduced to its ordinary state. We cannot, therefore, consider this as a gaseous compound of potassium and hydrogen.

When potassium is heated in hydrogen gas, there is a particular temperature intermediate between a red heat and the common temperature of the air, at which the metal absorbs the gas and is converted into a *hydret.* This hydret has a gray colour, and is destitute of the metallic lustre. It is infusible, and does not burn spontaneously either in common air or oxygen gas. In water it is converted into potash, and the hydrogen which it contains is disengaged along with what proceeds from the water decomposed.* According to Gay-Lussac and Thenard, to whom we are indebted for the discovery of this hydret, the quantity of hydrogen which potassium absorbs is rather more than $\frac{1}{4}$th of what it disengages from water when converted into potash. Now 100 grains of potassium evolve from water 116·4 cubic inches of hydrogen. The fourth part of 116·4 is 29·1. But 29·1 cubic inches of hydrogen gas weigh 0·629 grain. So that hydret of potassium is composed of

Potassium   .   .   100   .   5

Hydrogen   .   .   0·629 .   0·0314

But 0·0314 × 4 = 0·1256, which is very nearly equivalent to the weight of an atom of hydrogen. We have reason, therefore, to conclude that this hydret is a compound of 4 atoms potassium and 1 atom hydrogen. If so, its constituents are

Potassium   .   .   20

Hydrogen   .   .   0·125

———————

20·125

VII. Nothing is known respecting any compound which potassium may be capable of forming with azote.

VIII. The phenomena which take place during the preparation of potassium by Brunner's method, leave little doubt that potassium and carbon are capable of combining; though

* Recherches Physico-chimiques, i. 176.

carburet of potassium has neither been obtained in a state of purity, nor has its composition been determined. The black matter which remains in the retort after the distillation is over, certainly contains potassium united to carbon. When moistened with a little water it takes fire and burns. When thrown into water it is decomposed with effervescence. I tried to preserve it under naphtha; but was not successful. Probably the same carburet exists in the black matter which chokes up the iron tube during the preparation of potassium by Brunner's method.

IX. No experiments have hitherto been made to determine whether boron and potassium combine, or the nature of the boret.

X. Silicet of potassium is obtained when silica is decom- Silicet. posed by means of potassium. It is a brown substance, without any metallic lustre. When put into water hydrogen gas is evolved and silica formed.

XI. When potassium and phosphorus are heated together, Phosphuret. surrounded by an atmosphere of azotic gas, or in a vacuum, they unite, and in the act of combining the compound becomes red-hot. The same phosphuret is formed, when potassium is heated in phosphuretted hydrogen gas, pure hydrogen gas being left if the quantity of potassium be sufficient. This phosphuret, as formed, has a chocolate colour. It takes fire in the open air, and when thrown into water, the evolution of phosphuretted hydrogen gas is so rapid that a kind of explosion takes place. The phosphuret thus formed contains an excess of phosphorus. Rose informs us that when a current of hydrogen gas is passed over it, while heated in a glass tube, till all the excess of phosphorus is expelled, it crystallizes on cooling, has the metallic lustre, and the colour of copper. No attempts have yet been made to determine the composition of this compound. But there can be no doubt that phosphorus and potassium are capable of uniting in more than one proportion.

XII. For the investigation of the sulphurets of potassium Sulphurets. we are indebted to Berzelius, who has shown that the two constituents combine in no fewer than 5 different proportions.*

Sulphuret of potassium was known formerly by the name of *liver of sulphur*, and was considered as a compound of sulphur and potash. Berthollet first showed that when dissolved in water it contains sulphate of potash†. And he considered the

* Kongl. Vetens. Acad. Handl. 1821, p. 80.   † Ann. de Chim. xxv. 233.

solution as a mixture of sulphate of potash and hydrosulphuret of potash. In 1817, Vauquelin endeavoured to prove that when sulphur and potash are heated together, a part of the potash is converted into potassium, while at the same time a portion of the sulphur is acidified. Consequently that the compound obtained is a mixture of sulphuret of potassium and sulphate of potash.* This opinion was finally verified by the experiments of Berzelius above referred to.

Sulphuret.

1. *Sulphuret of potassium.* Berthier has shown that this compound is obtained by mixing sulphate of potash with charcoal powder, and exposing the mixture to a white heat in a covered crucible. It may be procured also by heating the same salt to redness in a glass or porcelain tube, and passing through it while in that state, a current of dry hydrogen gas. The oxygen by either of these processes is separated from the acid and the base, and the sulphur and potassium left in combination. When no more water appears the process is terminated. It is obvious (since sulphate of potash is a compound of 1 atom sulphuric acid and 1 atom potash), that this sulphuret is a compound of

1 atom sulphur	. .	2
1 atom potassium	. .	5
		7

It has a dark red colour like cinnabar, and is crystalline in its texture. It is not very combustible. When heated before the blow-pipe it burns for an instant, but is speedily covered by a thin coating of sulphate of potash, which protects the interior portion from the air. It absorbs moisture from the atmosphere, and runs into a yellowish liquid. Its solution in water is colourless.

If we mix together very intimately two parts of sulphate of potash and one part of lamp-black, and heat the mixture to whiteness in a covered crucible, we form a pyrophorus, the least particle of which scintillates when exposed to the air. It constitutes the pyrophorus of Homberg. The combustibility is owing in this case to the minute state of division of the sulphuret of potassium, and its intimate mixture with the excess of charcoal employed to reduce the sulphate.

This compound may be obtained in the liquid way by the following process contrived by Berzelius: Take a solution of caustic potash and divide it into two equal portions. Saturate

* Ann. de Chim. et de Phys. vi. 5.

one of these portions with sulphuretted hydrogen gas, put the saturated solution into a retort through which a current of hydrogen gas is made to pass, and heat it to drive off all excess of sulphuretted hydrogen gas. The potassium in this process combines first with sulphur* and afterwards with sulphuretted hydrogen. Or in reality (as I have found by experiment) the liquid contains a compound composed of

1 atom bisulphuretted hydrogen . .	5
1 atom potassium	5
	—
	10

When the other portion of caustic potash is added the whole is converted into sulphuret of potassium.† If we evaporate the liquid while a current of hydrogen gas passes over it, we obtain a thick colourless magma which does not crystallize. A little alcohol being added the sulphuret separates in the state of an oleaginous liquid, which is redissolved by an additional dose of alcohol. The taste of this liquid is exceedingly alkaline, and it acts as an alkali upon the epidermis and cuticle. It restores its blue colour to reddened litmus paper. Berzelius says that it does not remove the epidermis of the tongue, an experiment which I have not tried.

This sulphuret possesses the characters of a base, and unites with most of the sulphur acids into sulphur salts.

2. *Bisulphuret of potassium.* This compound is obtained by dissolving the hydrosulphuret of potassium in alcohol, leaving the solution exposed to the air, till it begins to become muddy on the surface, and then evaporating it to dryness in vacuo. This bisulphuret has an orange colour; its texture is not crystalline; it enters easily into fusion. Hydrosulphuret of potassium is a compound of 1 atom bisulphuretted hydrogen and 1 atom potassium. When the solution is exposed to the air the hydrogen in the first place absorbs oxygen, and is converted into water. The liquid becomes muddy on the surface as soon as the sulphur begins to unite to oxygen. It is obvious from this statement that bisulphuret of potassium is a compound of

2 atoms sulphur . .	4
1 atom potassium . .	5
	—
	9

---

* The hydrogen being employed to reduce the potassium.

† Because the atom of hydrogen is employed in converting the new dose of potash into potassium.

3. *Tersulphuret of potassium* is obtained by passing a current of bisulphuret of carbon vapour over carbonate of potash heated to redness as long as a permanent gas is disengaged. It may be obtained still more easily (but mixed with sulphate of potash) by heating a mixture of 35 parts of carbonate of potash and 20 parts (at least) of sulphur in a glass vessel, and keeping the mixture in a state of fusion at an incipient red heat, till the ebullition produced by the escape of carbonic acid gas is at an end. In this case the oxygen from three-fourths of the potash unites with and acidifies a quantity of sulphur exactly capable of saturating one-fourth of the potash, which continues unaltered. Thirty-five carbonate of potash contains 24 potash, which may be considered as the equivalent for 4 atoms. Eighteen or three of these atoms give out their oxygen and are reduced to potassium. The *three* oxygen thus disengaged unites with 2 sulphur, and converts it into sulphuric acid; which combines with the 6 potash still continuing unaltered. Thus we have

        Latin sulphate of potash 1 $\mathbf{f}$

3 atoms tersulphuret of potassium, $\begin{cases} 5 \times 3 = 15 \text{ potassium.} \\ 6 \times 3 = 18 \text{ sulphur.} \end{cases}$

It is obvious from all this that the sulphuret formed is a compound of

$$\begin{array}{ll} 3 \text{ atoms sulphur} & = 6 \\ 1 \text{ atom potassium} & = 5 \\ \hline & 11 \end{array}$$

So that its atomic weight is 11.

This is the sulphuret usually formed when sulphur and an alkaline carbonate are fused together. It is black and opaque while in a state of fusion; but when cold it has an hepatic colour, or the colour of common liver of sulphur. If we employ less than 8 sulphur, the whole carbonate of potash is not decomposed and continues mixed with the sulphuret. In such cases we have tersulphuret of potassium, mixed both with sulphate and carbonate of potash. If we expose such a mixture to a white heat, the carbonic acid gas is driven off and bisulphuret of potassium formed.

4. *Quatersulphuret of potassium* may be obtained by passing the vapours of bisulphuret of carbon over sulphate of potash heated to redness, till all disengagement of carbonic acid gas is at an end. Or we may fuse carbonate of potash with an excess of sulphur, and after driving off the excess of sulphur by heat,

pass a current of sulphuretted hydrogen over it at a red heat, till the sulphate of potash contained in it be completely decomposed.

This sulphuret resembles the preceding in appearance. From the analysis of Berzelius it is a compound of

4 atoms sulphur	. .	8
1 atom potassium	. .	5
		—
		13

So that its atomic weight is 13.

5. *Persulphuret of potassium* may be obtained by the following process: Mix together 35 parts of carbonate of potash and 32 parts of sulphur, and fuse the mixture in a glass vessel. The combination takes place at the temperature at which the sulphur fuses. In this case also, one quarter of the potash is converted into sulphate, while the other three-fourths are reduced to the state of potassium, and unite with the sulphur not acidified. The potash in 35 parts of carbonate weighs 24, equivalent to 4 atoms; the sulphur, 12, is equivalent to 6 atoms. Two sulphur unite to 3 oxygen, derived from the reduction of three atoms of the potash to potassium. The 5 sulphuric acid unite with 6 potash, and form 11 sulphate of potash. There remain 15 potassium and 30 sulphur, which obviously enter into combination. Dividing by 3 (because there are 3 atoms of potassium) we have 5 potassium and 10 sulphur, which is obviously equivalent to

5 atoms sulphur	. .	10
1 atom potassium	. .	5
		—
		15

So that its atomic weight is 15.

This persulphuret constitutes the common liver of sulphur of chemists. To obtain it free from all mixture of sulphate of potash, we have only to take one of the preceding sulphurets, formed by means of sulphuretted hydrogen or bisulphuret of carbon, and fuse it with an excess of sulphur, till all, except what enters into combination, is expelled.

It has a deep liver colour. It absorbs moisture from the atmosphere, and at the same time gives out the smell of sulphuretted hydrogen. When kept in badly corked phials it becomes white on the surface in consequence of the absorption of oxygen. Acids disengage from it sulphuretted hydrogen

gas, while sulphur precipitates. When poured into muriatic acid, not too strong, bisulphuretted hydrogen is disengaged. When heated with the metals, it converts them all, without exception, into sulphurets, and several of them have the property of uniting with the sulphuret of potassium, and forming with it a sulphur salt.

Besides these five sulphurets, for a knowledge of which we are indebted to Berzelius, there are two others, which seem to consist of two of these sulphurets united together.

6. The first is a compound of one integrant particle of ter-sulphuret, with one integrant particle of quatersulphuret. Berzelius obtained it by passing a current of sulphuretted hydrogen gas over red-hot sulphate of potash, till the formation of water by the mutual action of the gas and the salt are at an end. When cold this sulphuret is transparent, and has a fine wine red colour. According to the analysis of Berzelius it consists of

$3\frac{1}{2}$ atoms sulphur	.	.	.	7
1 atom potassium	.	.	.	5
				—
				12

Or it is a compound of

1 atom tersulphuret	.	.	11
1 atom quatersulphuret	.	.	13
			—
			24

This is equivalent to

2 atoms potassium	.	.	.	10
7 atoms sulphur	.	.	.	14
			—
			24

7. The other compound sulphuret is intermediate between the quatersulphuret and persulphuret. It was obtained by mixing quatersulphuret of potassium with sulphur, heating the mixture to incipient redness, and in that state passing a current of sulphuretted hydrogen over it, till no more sulphur is distilled over. According to the analysis of Berzelius it is a compound of

$4\frac{1}{2}$ atoms sulphur	.	.	9
1 atom potassium	.	.	5
			—
			14

Or we may consider it as a compound of

1 atom quatersulphuret	.	.	13
1 atom persulphuret	.	.	15
			—
			28

This is the same thing as

2 atoms potassium	.	.	10
9 atoms sulphur	.	.	18
			—
			28

Thus it appears that the sulphurets of potassium are as follows.

		Potassium.	Sulphur.			Atomic weight.
1.	Sulphuret	1 atom	+ 1 atom	.	.	7
2.	Bisulphuret	1	+ 2	.	.	9
3.	Tersulphuret	1	+ 3	.	.	11
4.	Quatersulphuret	1	+ 4	.	.	13
5.	Persulphuret	1	+ 5	.	.	15
6.	Ter-quatersulph.	2	+ 7	.	.	24
7.	Quater-persulph.	2	+ 9	.	.	28

XIII. When selenium and potassium are heated together Seleniet.
they combine with the evolution of a red heat, which sublimes
a portion of the compound. The seleniet of potassium has the
metallic lustre and the colour of iron. Its fracture is crystal-
line and radiated. It dissolves in water without the evolution
of any gas in consequence of the great solubility of selenietted
hydrogen gas in water. The liquid has a deep red colour.
Acids precipitate selenium from it.*

XIV. Arsenic combines readily with potassium by the Arseniet.
application of a moderate heat. Light is evolved during the
combination. This *arseniet* has a brown colour, and little of
the metallic lustre. When put into water much less hydro-
gen gas is evolved than would have appeared if the potassium
had not been alloyed with the arsenic. The reason is that a
portion of it remains combined with the arsenic, forming a
solid hydret of arsenic.†

XV. The alloy of tellurium and potassium may be obtained
by exposing a mixture of tellurate of potash and charcoal to a
strong heat in a well covered crucible.

XVI. Serullas formed the alloy, antimony and potassium, by Antimoniet.
exposing to a strong heat, an intimate mixture of equal weights
of bitartrate of potash and antimony in powder. The heat

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* Berzelius, Ann. de Chim. et de Phys. ix. 241.
† Gay-Lussac and Thenard. Recherches Physico-chimiques, i. 224.

must be at first gentle, and after every thing which is volatile at a red heat has been driven off, it must be raised and kept for some hours in a white heat. It has a grayish black colour, and is more porous, softer, and less brittle than antimony. When pounded it gives out sparks. When left exposed to the air it becomes hot, and burns the paper in which it was wrapt. It decomposes water and alcohol with considerable energy. Mercury separates the potassium and leaves the antimony.*

XVII. Nothing is known respecting the alloys which potassium may be capable of forming with chromium, uranium, molybdenum, tungsten, titanium, and columbium.

SECTION II.—OF SODIUM.

Soda. Soda, called also *fossil* or *mineral alkali*,† because it was thought peculiar to the mineral kingdom, was known to the ancients (though not in a state of purity) under the names of νῆτρον and *nitrum*.‡

Preparation. It is found in large quantity combined with carbonic acid in Egypt and some other parts of Africa, and combined with nitric acid in Peru; but the great source from which it is procured is common salt, which exists in vast quantity dissolved in the waters of the ocean, and constitutes thick beds deposited usually in the *new red sandstone* formation. Common salt is a *chloride* of sodium, and the soda of commerce which is now used in such quantities in Great Britain, is all extracted from common salt. The usual process is to convert the common salt into *sulphate of soda* by means of sulphuric acid. The sulphate of soda is heated with saw-dust or small coal, which reduces the salt to sulphuret of sodium.§ This sulphuret of sodium is heated in a furnace along with saw-dust, the sulphur gradually makes its escape, the sodium is oxidized and combines with the carbonic acid evolved. The matter is now digested in water, which is boiled down to the requisite consistency, and then allowed to crystallize in large flat iron ves-

* Ann. de Mines, vi. 127.

† Klaproth called it *natron,* and the German and Swedish chemists have followed his example.

‡ The λῆτρον of the Athenians was evidently the same substance; and so was the נתר of the Hebrews.

§ There are strong reasons for believing that during this part of the process, considerable quantities of sodium are driven off and lost. This I presume is the cause of the very considerable deficiency of the soda which a given weight of common salt ought to yield.

sels. The crystals are redissolved in water, and purified by a second crystallization. The carbonate of soda thus obtained is in large white crystals, and is a compound of

1 atom carbonic acid . .	2·75
1 atom soda ; . .	4·
10 atoms water . . .	11·25
	18·

It is never quite free from sulphate of soda; but the quantity present is small. Two hundred parts of the salt usually contain about 1 part of sulphuric acid.

Carbonate of soda was originally obtained from the ashes of different species of the *salsola*, a genus of plants which grow upon the sea-shore, especially from the *salsola soda*, from which the alkali has obtained its name. This impure soda is also called *barilla*, because the plant from which it is obtained bears that name in Spain. Almost all the algæ, especially the fuci, contain also a considerable quantity of soda. The ashes of these plants are known in this country by the name of *kelp*; in France they are called *varec*.

Soda and potash resemble each other so nearly that they were confounded together till Du Hamel published his dissertation on common salt in the Memoirs of the French Academy for 1736. He first proved that the base of common salt is soda, and that soda is different from potash. His conclusions were objected to by Pott, but finally confirmed by Margraff in 1758.*

Soda may be obtained from its carbonate in the state of hydrate by the very same process as potash. It has a grayish-white colour, and agrees exactly with potash in its taste, smell, and action upon animal bodies.

Heat produces on it exactly the same effects as upon potash. When exposed to the air, it absorbs moisture and carbonic acid, and is soon reduced to the consistence of paste; but it does not liquefy like potash; in a few days it becomes dry again, and crumbles into powder.

Many contradictory opinions respecting the component parts of soda were advanced by different chemists. At last, in 1808, Sir Humphry Davy succeeded in decomposing it, by the same process which enabled him to obtain the basis of potash. Like that alkali its basis is a metal, and Davy distinguished it by the name of *sodium*.†

* Opusc. ii. 331.
† The German and Swedish chemists call it *natrium* or *natron*.

Davy published a full account of its properties soon after its discovery.* Gay-Lussac and Thenard succeeded in procuring it in large quantities by the process described in the last section for obtaining potassium. They likewise examined its properties in detail, and published an elaborate account of them.† Berzelius made a set of very careful experiments in order to determine the proportions in which it combines with oxygen.‡

It is not so easy to obtain sodium by the process of Gay-Lussac and Thenard as it is to obtain potassium. Thenard informs us that the process is greatly facilitated by fusing in the first place the hydrate of soda with a little hydrate of potash; and the sodium when obtained is easily freed from the potassium by keeping it for some days in an open vessel, under a layer of rectified oil of turpentine or naphtha, which dissolves the potassium, but leaves the sodium untouched. Herman assures us, that if we employ tartrate of soda we may obtain sodium by Brunner's process with as much facility as potassium from cream of tartar.

Properties.

Sodium is a white metal, having a colour intermediate between that of silver and lead. At the common temperature of the air it is solid and very malleable, and so soft that pieces of it may be welded together by strong pressure. It retains its softness and malleability at the temperature of 32°. It is an excellent conductor of electricity. Its specific gravity is 0·97223.§ It melts when heated to the temperature of 194°,‖ and requires a much higher temperature to be volatilized than potash. Davy found it to remain fixed at a heat which melted plate glass.

Oxides.

II. Its affinity for oxygen is similar to that of potassium. When exposed to the air it speedily is converted on the surface to soda. As soda deliquesces much more slowly than potash, a globule of sodium is not so soon destroyed by exposure to the atmosphere as a globule of potassium. When put into water that liquid is rapidly decomposed; its hydrogen escapes in the state of gas while its oxygen converts the sodium into soda. When thrown upon water it does not take fire as potassium does. This Serullas ascribes to its great mobility compared to that of potassium. And he says that if sodium be placed in contact with a little water, thickened by gum, it is then

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* Phil. Trans. 1808, p. i.   † Recherches Physico-chimiques, i. 97.
‡ Ann. de Chim. lxxx. 245.
§ By the experiments of Gay-Lussac and Thenard. Davy makes it 0.9348. But his experiment was on a very minute scale.
‖ Gay-Lussac and Thenard.

arrested, and enough of heat is speedily generated to set the
sodium on fire. Sodium burns with a yellowish flame, while that
of potassium is reddish.* When a piece of sodium is thrown
on mercury, Serullas assures us that it is thrown off occasionally
by a small explosion, accompanied by the evolution of heat and
light, while nothing similar to this happens with potassium.

Sodium forms the same number of compounds with oxygen
that potassium does.

1. The *suboxide* is obtained in the same way as the suboxide
of potassium, which it resembles exactly in its characters, and
the same uncertainty exists whether it be a chemical compound,
or a mixture of sodium and soda.

2. Soda is formed when the metal is brought in contact with Soda.
water. From the experiments of Gay-Lussac and Thenard,
it appears that 38·394 grains of sodium, when converted into
soda by decomposing water, occasion the evolution of a quan-
tity of hydrogen gas, which, at the temperature of 60°, and
when the barometer stands at 29·882 inches, amounts to
76·437 cubic inches.† Therefore, supposing the barometer at
30 inches, the amount would be 76·14 cubic inches. Conse-
quently 100 grains of sodium would cause the evolution of
198·30 cubic inches of hydrogen gas. The quantity of oxygen
which united to the sodium to convert it into soda must have
been equivalent to 99·15 cubic inches, amounting in weight to
34·295 grains. According to these data, soda is composed of

<div style="text-align:center">

Sodium   .   .   100
Oxygen   .   .   34·295

</div>

Berzelius found that 100 sodium, when converted into soda,
combine with 34·61 parts of oxygen,‡ which he afterwards
corrected into 34·52.§ Davy says, that from a careful set of
experiments which he made on the subject, he found soda a
compound of from 75 to 73 sodium, and from 25 to 27 oxygen.||
Now the mean of the experiments of Gay-Lussac and Thenard,
and of those of Berzelius, give 34·4 as the quantity of oxygen;
while one of Davy's results is 33⅓. I think, therefore, we
cannot hesitate to conclude that sodium, in order to be con-
verted into soda, must combine with exactly one-third of its
weight of oxygen. Hence soda is composed of

<div style="text-align:center">

Sodium   .   .   100
Oxygen   .   .   33·3

</div>

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* Ann. de Chim. et de Phys. xl. 329.
† Recherches Physico-chimiques, i. 121.   ‡ Ann. de Chim. lxxx. 251.
§ Annals of Philosophy, iii. 360. || Ann. de Chim. lxxx. 251.

If we consider soda as a compound of 1 atom sodium and 1 atom oxygen, the weight of an atom of sodium will be 3, and the weight of an atom of soda 4.

Pure soda has a gray colour, is a non-conductor of electricity, has a vitreous fracture, and requires a strong red heat to melt it. When a little water is added the soda combines with it rapidly, evolving considerable heat; it becomes at the same time white, crystallized in its texture, and much more fusible than formerly. In this state it is a hydrate of soda, which, when pure, is a compound of 1 atom soda and 1 atom water, or is composed by weight of

Soda	.	. 4	.	.	100
Water	.	. 1·125	.	.	28·1

D'Arcet's analysis gives us the hydrate of soda composed of 100 soda + 38·8 water,* while that of Berard gives its composition 100 soda + 23·2 water.† Now the mean of these two gives 100 soda + 31 water, which differs as little as can well be expected from the theoretic number, when we consider the strong tendency that soda has to unite with more water. It dissolves very readily in water, and may be obtained in crystals by evaporating the aqueous solution.

The following table by Dalton exhibits the weight of soda contained in aqueous solutions of different specific gravities:

Sp. gravity.	Soda per cent.	Boiling point.	Sp. gravity.	Soda per cent.	Boiling point.
2·00	77·8		1·40	29·0	242°
1·85	63·6	600°	1·36	26·0	335
1·72	53·8	400	1·32	23·0	228
1·63	46·6	300	1·29	19·0	224
1·56	41·2	280	1·23	16·0	220
1·50	36·8	265	1·18	13·0	217
1·47	34·0	255	1·12	9·0	214
1·44	31	298	1·06	4·7	213

Peroxide.   3. The peroxide of sodium was discovered by Gay-Lussac and Thenard. It is easily formed by heating sodium in oxygen gas. It burns with great splendour, and combines with a maximum of oxygen.

The peroxide of sodium, when pure, is of a dirty greenish yellow colour. It is fusible when heated, but requires a much higher temperature than the peroxide of potassium for its fusion. When introduced into water, it is reduced to soda, giving out the excess of oxygen which it contains. From the experiments

* Ann. de Chim. lxviii. 175, and lxxi. 20.   † Ann. de Chim. lxxii. 96.

of Gay-Lussac and Thenard, it appears, that sodium in the peroxide is united with $1\frac{1}{2}$ times as much oxygen as in soda.* Hence it is composed of

1 atom sodium	.	.	3
$1\frac{1}{2}$ atom oxygen •	.	.	1·5

			4·5

III. Chlorine and sodium unite with great energy, forming *chloride of sodium.*

Chloride.

When sodium is introduced into chlorine gas, it takes fire spontaneously and burns vividly, emitting bright red sparks. The substance formed is *chloride of sodium.* It may be formed likewise, by passing a current of chlorine gas over soda, previously heated to redness. The soda gives out its oxygen in the state of gas, and is converted into a chloride.† It is composed of

1 atom chlorine	.	.	4·5
1 atom sodium	.	.	3

			7·5

It has been long known under the name of *common salt,* and will be described in a subsequent part of this work, as will also the bromide and iodide of sodium, which also possess the characters of salts.

IV. The combinations of sodium with carbon, boron, silicon, phosphorus, sulphur, selenium, &c. are so similar to the compounds of the same bodies with potassium that it seems unnecessary to enter into any details respecting them.

V. Sodium unites with arsenic when placed in contact with it, and raised to a cherry-red heat. A feeble light is emitted at the moment of combination. An alloy of 1 volume sodium and 3 volumes of arsenic has a grayish white colour, is brittle, is fine granular, and has a strong taste. It is rapidly decomposed in the open air. When put into water it is soon separated into soda and a brown powder which is a hydret of arsenic. Some hydrogen gas, likewise, makes its escape. An alloy of 2 volumes sodium and 1 volume arsenic has a brown colour and earthy aspect without any metallic lustre. Water produces on it the same effects as upon the last-mentioned alloy.‡

Arseniet.

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* Recherches Physico-chimiques, i. 152. † Davy.
‡ Recherches Physico-chimiques, i. 244.

The alloy of sodium and antimony is very similar to that of potassium and antimony.

No experiments have been made to determine the nature of the alloys which sodium may form with chromium, uranium, molybdenum, tungsten, columbium, and titanium.

SECTION III.—OF LITHIUM.

History. In the mine of Uto in Sweden there occurs a mineral which was first distinguished by D'Andrada, under the name of *Petalite;* but which, though known to mineralogists for several years, has only lately attracted the attention of chemists.

1. This mineral has never been found crystallized; but a twofold cleavage may be observed in it parallel to the faces of a rhomboidal prism. One of these cleavages is splendent, and the other dull. The two diagonals of a rhomboidal face are, according to Haüy, to each other as $\sqrt{13} : \sqrt{2}$; consequently the opposite angles are 137° 8′, and 42° 52′.* Its colour is white with a very faint tinge of red, or blue, or green. Its longitudinal fracture is foliated, the cross fracture small conchoidal, or sometimes fibrous. Its external lustre approaches the pearly; but internally the lustre is nearly vitreous. Its specific gravity, according to Arvedson, is 2·42. It is translucent, and in thin pieces nearly transparent; and it refracts singly at least when the object is seen through parallel faces of the mineral. Its hardness seems to be very nearly the same as that of felspar. It readily scratches glass. Felspar is not capable of scratching it. Before the blow-pipe its fusibility is nearly the same as that of adularia. The glass when completely fused is transparent, interspersed with small air-bubbles. It melts into a colourless glass with borax. And when digested in acids, it is partly decomposed. This mineral drew the attention of Arvedson, a pupil of Berzelius, who found it composed of silica, alumina, and an alkali. A loss of weight, which took place in three several analyses, induced him to examine the nature of this alkali. He found its properties peculiar, and, at the suggestion of Berzelius, distinguished it by the name of *lithia.*†

There are several other minerals in which this alkali is found, though always in small quantity. *Spodumene* is the most productive; though even in that mineral the quantity

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* Ann. de Chim. et de Phys. x. 84.

† From λίθος, a stone. See his experiments, Kongl. Vetensk. Acad. Handl. 1818, p. 23. Gmelin's experiments are in Gilbert's Annalen, lxii. 405.

does not amount to 8 per cent. It exists also in *ambligonite*, which is a double phosphate of alumina and lithia. The *tour-maline* likewise contains it, and also the variety of mica called *lepidolite*. Dr. Turner has observed that its presence may be discovered by the blow-pipe, by mixing the assay with a little fluor spar, or with bisulphate of potash and fluor spar pounded together. The lithia is disengaged, and tinges the flame of a tallow candle *red*.*

•The easiest method of extracting the lithia from any of these minerals (except ambligonite) is to mix the mineral (previously reduced to a fine powder) with a quantity of fluor spar, also in fine powder equal to $2\frac{1}{2}$ times the weight of the silica which the mineral contains. This mixture is put into a silver crucible, and made up into a paste with sulphuric acid. It is then heated at first gently, and when the greatest part of the fluosilicic acid has made its escape, the heat is to be raised to redness to drive off all excess of sulphuric acid, and to decompose the sulphate of alumina. The dry mass being now lixiviated with water, a solution of sulphate of lithia will be obtained, mixed with a little sulphate of lime. The sulphate of lime may be separated by careful evaporation and crystallization, or the lime may be thrown down at once by oxalate of ammonia. Should the sulphate of alumina not have been decomposed by the heat, the alumina may be thrown down by digesting the liquid with carbonate of lime, and the sulphate of lithia obtained in a state of purity. The lithia may be thrown down from this sulphate in the state of carbonate by means of carbonate of ammonia or carbonate of soda. We must not use carbonate of potash, otherwise the lithia will be contaminated with that alkali, which has the property of forming double salts with lithia.

Or we may separate the sulphuric acid by adding barytes water, taking care to avoid all excess. The liquid being filtered and evaporated to dryness, we obtain the lithia in the state of an hydrate.

II. Lithia thus obtained has a white colour, converts vegetable blues to green, and has a taste fully as caustic as that of potash itself. At a red heat it melts and becomes a transparent liquid. When exposed to the air it does not attract moisture, like potash; but remains dry. But it gradually absorbs carbonic acid, and is converted into a carbonate. It is but little soluble in water, compared with potash or soda, though the exact degree

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* Annals of Philosophy (2d series), xi. 131.

of solubility has not been ascertained. Gmelin found it scarcely soluble in alcohol of the specific gravity 0·85, and when alcohol is added to an aqueous solution, the lithia precipitates after an interval of some hours. When heated in a platinum crucible, it acts with considerable energy upon that metal.

Lithium.

Sir Humphry Davy succeeded by means of a Voltaic battery in extracting from lithia its metallic basis. He found it to bear a strong resemblance to the other alkaline metals, especially to *sodium;* to which it appears to be the most nearly allied. Both Arvedson and Gmelin tried this reduction by means of galvanism, but without success.

The experiments of Arvedson,[*] Gmelin,[†] Vauquelin,[‡] Stromeyer,[§] and my own,[||] to determine the atomic weight of lithia, were inaccurate, and the error was the same in all, indicating that it proceeded in all from the same cause. This cause has been recently pointed out by M. R. Hermann of Moscow. It proceeded from the circumstance that the lithia analyzed was not pure, but in the state of a double salt from the presence of potash. Hermann prepared a quantity of pure carbonate of lithia by precipitating it from the sulphate or muriate, by means of carbonate of ammonia and carbonate of soda; both of which threw down the lithia in the state of a pure carbonate. In two successive experiments he obtained the composition of neutral carbonate of lithia as follows:

Atomic weight.

Carbonic acid · · · ·	60·98 · ·	61
Lithia · ·	39·02 · ·	39[¶]
	100·00	100

If we consider this salt as a compound of one atom carbonic acid and one atom lithia, the preceding analysis gives us the atomic weight of *lithia* 1·758. For 61 : 39 :: 2·75 (atom of carbonic acid) : 1·758 = atom of lithia.

Hermann also analyzed sulphate of lithia, and found the constituents to be

Sulphuric acid · ·	74
Lithia · · ·	26
	100[**]

This gives us 1·7567 for the atomic weight of lithia.

* Kongl. Vet. Acad. Handl. 1818, p. 23.
† Gilbert's Annalen, lxii. 405. ‡ Ann. de Chim. et de Phys. vii. 287.
§ Untersuchungen, i. 435. || First Principles, i. 265.
¶ Poggendorf's Annalen. xv. 481. ** Ibid. p. 482.

He analyzed also the chloride of lithium, which he found a compound of

Chlorine . .	85·34
Lithium .	14·66
	————
	100·00*

This gives 0·8571 for the atomic weight of lithium. There can be no doubt, from a comparison of these analyses, that lithia is a compound of 1 atom lithium and 1 atom oxygen. The mean of the three analyses gives us 0·79 for the atomic weight of lithium, and 1·79 for the atomic weight of lithia. But if we take the analyses of the carbonate and sulphate as likely to be most exact, then the atomic weight of lithium will be 0·75, and that of lithia 1·75.

Berzelius repeated the analyses of Hermann with a quantity of the carbonate of lithia sent him by that chemist. He has not given us the experiments, but merely informs us that he found lithia a compound of

Lithium . .	44·846 or 100
Oxygen . .	55·154 or 123
	————
	100†

This would make the atomic weight of lithium 0·813, and that of lithia 1·813. These different analyses leave it doubtful whether the atomic weight of lithium be 0·75 or 0·875. Meanwhile we cannot be far from the truth if we assume 0·75 as the atomic weight of lithium, and 1·75 as the atom of lithia. It is, therefore, by far the lightest of all the alkaline bases.

Lithium combines with chlorine, and forms a compound Chloride. which may be called a chloride of lithium. It has not been formed directly, but may be obtained by saturating lithia with muriatic acid, evaporating the solution to dryness and exposing the dry salt to heat while the air is excluded. The muriate of lithia does not crystallize, but forms a crust. It deliquesces very rapidly when exposed to the air. When heated, it melts at a very low temperature. The chloride when exposed to the air speedily attracts moisture.

The compounds of lithium with bromine, iodine, hydrogen, azote, carbon, boron, silicon, phosphorus, selenium, and the metals have not been hitherto examined. The sulphate of lithia may be converted into sulphuret of lithium by means of

* Poggendorf's Annalen. p. 484.   † Chimie. ii. 319.

hydrogen gas, precisely as sulphate of potash.   When reduced to a sulphuret by means of an excess of charcoal, it is a powerful pyrophorus.

SECTION IV.—OF BARIUM.

History.   Barytes was discovered by Scheele in 1774; and the first account of its properties published by him in his Dissertation on Manganese.*   There is a very heavy mineral, most frequently of a flesh colour, of a foliated texture and brittle, very common in Britain and most other countries, especially in copper mines. It was known by the name of *ponderous spar*, and was supposed to be a compound of sulphuric acid and lime. Gahn analyzed this mineral in 1775, and discovered that it is composed of sulphuric acid and the new earth discovered by Scheele.†   Scheele published an account of the method of obtaining this earth from ponderous spar.‡   The experiments of these chemists were confirmed by Bergman,§ who gave the earth the name of *terra ponderosa*.   Morveau gave it the name of *barôte*, and Kirwan of *barytes;*‖ which last was approved of by Bergman,¶ and is now universally adopted.   Different processes for obtaining barytes were published by Scheele, Bergman, Wiegleb, and Afswelius; but little addition was made to the properties ascertained by the original discoverer, till Dr. Hope published his experiments in 1793.**   In 1797, our knowledge of its nature was still farther extended by the experiments of Pelletier, Fourcroy, and Vauquelin.††

Extraction.   Barytes may be obtained from ponderous spar, or sulphate of barytes, as it is now called, by the following process, for which we are indebted to Scheele and Vauquelin.   Reduce the mineral to a fine powder; mix it with the eighth part of its weight of charcoal powder, and keep it for some time red-hot in a crucible, and it will be converted into sulphuret of barytes.   Dissolve the sulphuret in water, and pour nitric acid into the solution, and the sulphur will be precipitated. The solution, which consists of nitric acid combined with barytes, is to be filtered and evaporated slowly till it crystallizes.   Put the crystals into a crucible, and expose them gradually to a strong

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* Scheele, i. 61 and 78; French Translation.
† Bergman's Notes on Scheffer, § 167. p. 194.
‡ Crell's Annals, iii. 3. Eng. Trans.   § Opus. iii. 291.
‖ From Βαρυς, heavy.   ¶ Opusc. iv. 261.
** Edin. Trans. iv. 36.   †† Ann. de Chim. xxi. 113 and 276.

heat; the nitric acid is driven off, and the barytes remains in a state of purity.*

Another method, attended with less expense, was pointed out long ago by Dr. Hope, and afterwards improved by Pelletier. The method is this : Decompose the sulphate of barytes by heating it strongly along with charcoal powder. The product is to be treated with water to dissolve every thing that is soluble ; and the liquid, being filtered, is to be mixed with a solution of carbonate of soda. A white powder falls. Wash this powder, make it up into balls with charcoal, and heat it strongly in a crucible. When these balls are treated with boiling water, a portion of barytes is dissolved, which crystallizes as the water cools.

Barytes obtained by the first method is a grayish-white porous body, which may be very easily reduced to powder. It has a harsh and more caustic taste than lime ; and when taken into the stomach proves a most violent poison. It has no perceptible smell. It tinges vegetable blues green, and decomposes animal bodies like the fixed alkalies, though not with such energy.

Its specific gravity, according to Fourcroy,† is 4; but according to Hassenfratz only 2·374.‡ But there is reason to conclude, from the method employed by this philosopher, that the specific gravities which he assigns are all too low.

When heated it becomes harder, and acquires internally a bluish-green shade. When exposed to the blow-pipe on a piece of charcoal, it fuses, bubbles up, and runs into globules, which quickly penetrate the charcoal.§ This is probably in consequence of containing water, for Lavoisier found barytes not affected by the strongest heat which he could produce. Gehlen and Bucholz have ascertained that when crystals of barytes are exposed to heat, they speedily melt and give out water. When the heat is raised to redness they again undergo fusion, and assume the appearance of an oil. But this experiment does not succeed with barytes, obtained from the nitrate, by Vauquelin's process. This difference, they showed, is not owing to the presence of carbonic acid, or of any earthy matter from the crucible in the barytes from the nitrate.‖ The fusi-

* When thus prepared, it always contains about 0·08 of carbonate of barytes, and sometimes much more.
† Fourcroy, ii. 189. ‡ Ann. de Chim. xxviii. 11.
§ Fourcroy and Vauquelin, Ann. de Chim. xxi. 276.
‖ Gehlen's Journal für die Chimie, Physik und Mineralogie, iv. 258.

bility, in the first case is owing to the barytes retaining a portion of water.*

It had been suspected, by Bergman, that barytes was a metallic oxide.† But no attempts to detect its supposed metallic basis were attended with any success, till after the analysis of potash and soda, by Davy, in 1808. This immediately led to the idea that all the earths were likewise metallic oxides. Berzelius and Pontin first succeeded in decomposing barytes, by exposing a globule of mercury to the action of negative electricity, while placed upon moistened barytes on a platinum plate; an amalgam of the metal of barytes was formed. Davy repeated these experiments, and by distilling the amalgam, succeeded in obtaining small quantities of the metal of barytes, to which he gave the name of *barium*.

Barium.

Barium, thus obtained, is a solid metal of the colour of silver, it melts at a temperature below redness, and is not volatalized by a heat capable of melting plate glass, but at that temperature it acts violently upon the glass; probably decomposing the alkali of the glass. When exposed to the air it rapidly tarnishes, absorbs oxygen, and is converted into barytes. It sinks rapidly in water, and seems to be at least four or five times heavier than that liquid. It decomposes water with great rapidity; hydrogen is emitted, and it is converted into barytes. When strongly pressed it becomes flat, and hence appears to be both ductile and malleable.

Oxides.

II. From the experiments of Gay-Lussac and Thenard, we learn that barium combines with two proportions of oxygen, forming two oxides which have been called *barytes* and *peroxide of barium.*

Barytes.

1. Barytes is the substance formed when barium is put into water. It has been known since the year 1774, and is found abundantly in the mineral kingdom, combined sometimes with carbonic acid, but much more frequently with sulphuric acid.

Barytes is a grayish white substance, having an acrid and alkaline taste, rendering vegetable blues green, and acting as a virulent poison.

When exposed to the air, it immediately attracts moisture; in consequence of which it swells, heat is evolved, and the barytes falls to a white powder, just as happens to quicklime

* This I think follows evidently from the experiments of Gay-Lussac and Thenard. See Recherches Physico-chimiques, i. 170.

† Opusc. iv. 212.

when water is sprinkled on it.* After the barytes is thus *slacked*, it gradually attracts carbonic acid, and loses its acrid properties, its weight being increased 0·22.† It cannot, therefore, be kept pure except in close vessels.

When a little water is poured upon barytes, it is slacked like quicklime, but more rapidly, and with the evolution of more heat. The mass becomes white, and swells considerably. If the quantity of water be sufficient to dilute it completely, the barytes crystallizes in cooling, and assumes the appearance of a stone composed of needle-form crystals; but when exposed to the air, it gradually attracts carbonic acid, and falls to powder.‡

Water is capable of dissolving 0·05 parts of its weight of barytes. This solution, which is known by the name of *barytes water*, is limpid and colourless, has an acrid taste, and converts vegetable blues first to a green and then destroys them. When exposed to the air, its surface is soon covered with a stony crust, consisting of the barytes combined with carbonic acid.

Hydrates.

Boiling water dissolves more than half its weight of barytes. As the solution cools, the barytes is deposited in crystals; the shape of which varies according to the rapidity with which they have been formed. When most regular, they are flat hexagonal prisms, having two broad sides, with two intervening narrow ones, and terminated at each end by a four-sided pyramid, which in some instances constitutes the larger part of the crystal. When formed slowly, they are distinct and large; but when the water is saturated with barytes, they are deposited rapidly, and are generally more slender and delicate. Then, too, they are attached to one another in such a manner as to assume a beautiful foliacious appearance, not unlike the leaf of a fern.§

These crystals are transparent and colourless, and appear to be composed of about 53 parts of water and 47 of barytes. When exposed to the heat of boiling water, they undergo the *watery fusion;* that is to say, the water which they contain becomes sufficient to keep the barytes in solution. A stronger heat drives off part of the water, but not the whole. When exposed to the air, they attract carbonic acid, and crumble into dust. They are soluble in $17\frac{1}{2}$ parts of water at the temperature of 60°; but boiling water dissolves any quantity whatever:

* Fourcroy and Vauquelin, Ann. de Chim. ii. 59.
† Mem. de l'Institut. ii. 59.   ‡ Fourcroy, ii. 193.
§ Hope, Edin. Trans. iv. 36.

the reason of which is evident; at that temperature their own water of crystallization is sufficient to keep them in solution.*

It was observed by Bucholz and Gehlen that when the crystals of barytes are exposed to heat, they readily melt in their water of crystallization. As this water evaporates the barytes is reduced to a dry mass. This mass again melts when heated to redness and flows like an oil. But barytes procured from the nitrate of that earth by heat is infusible in the strongest heat that can be raised in our furnaces.† The reason of this difference is that the barytes obtained by heat from the crystals is in the state of *hydrate*, while the earth from the nitrate is free from water. From the experiments of Dalton, it appears, that water combines in at least 3 proportions with barytes, and forms 3 solid hydrates.

	Barytes.	Water.
1st composed of	1 atom +	1 atom.
2d	1	+ 5
3d	1	+ 20

The first is formed by exposing crystallized barytes to a strong red heat; the second by reducing the crystals to a dry powder by heat; and the third consists of crystallized barytes.‡

Mr. Barry has observed that when concentrated sulphuric acid is poured upon caustic barytes, ignition ensues.§

Atomic weight. I had from a set of experiments in which dry chloride of barium was decomposed by sulphate of potash, inferred that the atomic weight of barytes was 9·75. The conclusion was founded upon this experiment, 13·25 grains of chloride of barium were mixed with 11 grains of sulphate of potash, both in solution, and it was found that after the sulphate of barytes had precipitated, the residual liquid contained no sensible quantity of sulphuric acid or of barytes. Berzelius, in the third volume of his Lärbok i Kemien, stated that when these proportions were used, there always remained an excess of barytes. I requested several of my practical pupils to repeat the experiment without mentioning my object, and they all gave me the same proportions of the two salts that I had previously stated. I was induced in April, 1828, to try the experiment anew, and for this purpose prepared a quantity of pure chloride of barium, and of sulphate of potash. After repeating the experiment about 30 times, varied in every pos-

* Hope, Edin. Trans. iv. 36.
† Gehlen's Journal für die Chemie, Physik und Mineralogie, iv. 258.
‡ New System of Chemical Philosophy, ii. 522.
§ Annals of Philosophy (2d series), ii. 77.

sible way, I found myself quite unable to determine the exact proportions of the two salts which decompose each other. There was no difficulty in finding the proportions, which, when mixed together, leave no sensible residue of sulphuric acid and barytes in solution. But when I attempted to collect the sulphate of barytes and chloride of potassium, I never found the quantities to agree in any two consecutive experiments. Suspecting that the method of using double filters might be the cause of the uncertainty, I substituted single filters of Indian paper, which were finally burnt in platinum crucibles.* I was therefore obliged to give up the attempt of determining the atomic weight of barytes by this method. Dr. Turner has since explained the cause of this failure, which, indeed, I suspected at the time. It is owing to a portion of the sulphate of potash adhering obstinately to the sulphate of barytes, and thus escaping decomposition.† Foiled in this, I substituted sulphate of ammonia, and afterwards sulphuric acid. By mixing a solution, containing a given weight of chloride of barium with an excess of sulphate of ammonia or of sulphuric acid, evaporating to dryness, and then exposing the residual salt to a strong red heat, I succeeded in determining the weight of sulphate of barytes, which is the equivalent for a given weight of chloride of barium. The same weight of chloride of barium was afterwards decomposed by nitrate of silver, and the weight of chlorine determined from my old data that chloride of silver is a compound of

Silver	.	13·75
Chlorine	.	4·5
		————
		18·25

The result of these trials (which occupied me for several weeks) was that sulphate of barytes is a compound of

Sulphuric acid	. .	5
Barytes	. . .	9·5006

Now as 5 is the atomic weight of sulphuric acid, it is clear that 9·5 must be the atomic weight of barytes.‡

From the experiments of Davy on the chloride of barium,

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* The same weight of India paper leaves almost exactly the same weight of ashes. On that account I sometimes employ it in delicate experiments, when a double filter is not sufficiently accurate for the object in view.

† Phil. Trans. 1829.

‡ These experiments of mine are confirmed by those of M. de Saussure, (published a few weeks ago), which certainly do not differ so much as $\frac{1}{1000}$th part from mine. See Ann. de Chim. et de Phys. xliv. 25.

it is obvious that barytes is a compound of 1 atom barium +
1 atom oxygen. Consequently the atomic weight of barium
must be 8·5.

Peroxide.
2. Gay-Lussac and Thenard found that when dry barium
from nitrate of barytes, or from the carbonate of barytes, decom-
posed by charcoal, is heated in oxygen gas; it absorbs that
gas with great rapidity. The peroxide formed is gray. It
gives out its excess of oxygen when put into an acid liquid.
When heated in hydrogen gas the hydrogen is absorbed and
water formed, which remains united to the barytes.*

It may be formed also by passing a current of dry oxygen
gas over red-hot barytes as long as it continues to absorb that
gas. When pulverized and put into water, it is converted
into a hydrate without the evolution of any heat. It is then a
snow-white powder. The peroxide of barium is not decom-
posed by exposure to a red heat, but it is decomposed by boil-
ing water. Thenard has shown that when nitrate of manga-
nese, copper, &c. are mixed with the hydrated peroxide of
barytes, the metallic bases are peroxidized. It was by means
of peroxide of barium that Thenard succeeded in forming deut-
oxide of hydrogen.

According to Thenard peroxide of barium is a compound of

1 atom barium	. .	8·5
2 atoms oxygen	. .	2
		10·5

and its atomic weight is 10·5.

III. The chloride, bromide, and iodide of barium, possess the
characters of salts. They will fall to be described in the second
volume of this work.

IV. Nothing is known respecting the compounds which
barium may be capable of forming with hydrogen, carbon,
boron, or silicon.

Phosphuret.
V. When vapour of phosphorus is made to pass over barytes
heated to redness, a portion of the phosphorus is acidified, and
combines with a portion of the barytes. The barytes thus
reduced to the metallic state combines with phosphorus and
forms a phosphuret of barium. The colour of this phosphuret
is dark brown, and its lustre almost metallic. This phosphuret
is decomposed by exposure to a strong heat. It is decomposed
also by water, phosphuretted hydrogen gas being evolved, and
hydrophosphite of barytes formed, as M. Dulong first dis-

* Recherches Physico-chimiques, i. 169.

covered.   M. Dumas found that when 74·04 parts of barytes were thus converted into phosphuret, the weight became 100.* Now if we suppose $3\frac{1}{2}$ atoms of barytes, and that $2\frac{1}{2}$ atoms part with their oxygen to convert an atom of phosphorus into phosphoric acid, which unites with the atom of barytes that remains unaltered, while every atom of barium unites with two atoms of phosphorus, the result will agree nearly with the experiment of Dumas.   For

$$
\begin{array}{lll}
3\cdot5 & \text{atoms barytes} & = 33\cdot25 \\
1 & \text{atom phosphorus} \\
2\frac{1}{2} & \text{atoms oxygen} & \Big\} = 4\cdot5 \ \text{ phosphoric acid,} \\
1 & \text{atom barytes} & = 9\cdot5 \\
\hline
 & & 14 \quad \text{phosphate of barytes,} \\
2\cdot5 & \text{atoms barium} & = 21\cdot25 \\
5 & \text{atoms phosphorus} & = 10\cdot0 \\
\hline
 & & 31\cdot25 \ \text{biphosphuret of barium,}
\end{array}
$$

Barytes   .   .   33·25
Phosphuret and phosphate 45·25

Now 33·25 : 45·25 :: 74·04 : 100·76; numbers which come exceedingly near those of Dumas, since the difference does not amount to 1 per cent.   There seems no reason to doubt, then, that in this process there are formed

2·5 atoms biphosphuret of barium   .   .   31·25
1 atom phosphate of barytes   .   .   14

So that somewhat less than $\frac{5}{7}$ths of the whole is biphosphuret of barium, and somewhat more than $\frac{2}{7}$ths phosphate of barytes.

VI. Barium, like potassium, combines with sulphur in various proportions; but the constitution of these sulphurets has not yet been determined analytically.   The colour of these sulphurets, such of them at least as I have formed, is very similar to that of alkaline liver of sulphur.   The processes which have been followed for making these sulphurets are the following :

Sulphurets.

1. When sulphate of barytes in powder is mixed with charcoal, and heated to redness in a covered crucible, the oxygen of both the constituents of the salt is carried off in combination with the carbon, and a sulphuret of barium remains.   The sulphuret thus formed dissolves in boiling water, and the saturated solution gives fine transparent and colourless crystals. It is by dissolving this sulphuret in acids that the different salts of barytes are usually formed.   During its solution it

* Ann. de Chim. et de Phys. xxxiii. 364.

gives rather more than the fifth part of its weight of sulphuretted hydrogen gas.

2. If we mix caustic barytes and sulphur together, and heat the mixture to redness in a covered crucible, we obtain sulphuret of barium mixed with a little sulphate of barytes. Three-fourths of the barytes are converted into barium; the other fourth into sulphate of barytes.

3. We may obtain sulphuret of barytes in a state of purity by passing a current of dry sulphuretted hydrogen gas over barytes, ignited in a glass tube, till all formation of water is at an end. The barytes assumes a red colour till it is completely converted into sulphuret of barium, when it assumes the brown colour of that compound.

When the solution of sulphuret of barium is boiled with sulphur, we obtain a compound consisting of 5 atoms sulphur united to 1 atom barium, or it consists of

Sulphur . .	10
Barium . .	8·5
	18·5

VII. Nothing is known respecting the compounds of selenium and barium; nor respecting the alloys which it may be capable of forming with the different metals.

SECTION V.—OF STRONTIUM.

About the year 1787 a mineral was brought to Edinburgh, by a dealer in fossils, from the lead ' mine of Strontian, in Argyleshire, where it is found imbedded in the ore, mixed with several other substances. It is sometimes transparent and colourless, but generally has a tinge of yellow or green. It is soft. Its specific gravity varies from 3·4 to 3·726. Its texture is generally fibrous; and sometimes it is found crystallized in slender prismatic columns of various lengths.*

This mineral was generally considered as a carbonate of barytes; but Dr. Crawford having observed some differences between its solution in muriatic acid and that of barytes, mentioned in his treatise on *muriate of barytes,* published in 1790, that it probably contained a new earth, and sent a specimen to Mr. Kirwan, that he might examine its properties. Dr. Hope made a set of experiments on it in 1791, which were read to the Royal Society of Edinburgh in 1793, and published in the

* Hope, Edin. Trans. iv. 14.

Transactions about the beginning of 1794. These experiments demonstrate, that the mineral is a compound of carbonic acid, and a peculiar earth, whose properties are described. To this earth Dr. Hope gave the name of *strontites*. Klaproth analyzed it also in 1793, and drew the same conclusions as Dr. Hope, though he was ignorant of the experiments of the latter, which remained still unpublished. Klaproth's experiments were published in Crell's Annals for 1793* and 1794.† Kirwan also discovered the most interesting peculiarities of this new earth in 1793, as appears by his letter to Crell, though his dissertation on it, which was read to the Irish Academy in 1794, was not published till 1795. The experiments of these philosophers were repeated and confirmed in 1797 by Pelletier, Fourcroy, and Vauquelin,‡ and several of the properties of the earths till farther investigated. To the earth thus detected Klaproth gave the name of *strontian*, from the place where it was first found; and this name is now generally adopted.

Strontian is found abundantly in different parts of the world, and always combined with carbonic acid or sulphuric acid.

The carbonic acid may be expelled from the carbonate, and the strontian obtained pure, by mixing the mineral with charcoal powder, and exposing it to a high temperature, or by dissolving the mineral in nitric acid, evaporating the solution till it crystallizes, and exposing the crystals in a crucible to a red heat till the nitric acid is driven off. Strontian may be obtained from the sulphate by following exactly the process described in the last section for obtaining barytes.

Strontian, thus obtained, is in porous masses, of a grayish white colour; its taste is acrid and alkaline; and it converts vegetable blues to green. It does not act so strongly on animal bodies as barytes, nor is it poisonous.§

Davy, after his discovery of the metallic nature of potash and soda, was naturally led to consider strontian as a metallic oxide, as well as barytes and lime. He succeeded in decomposing it by the same processes as have been detailed in the preceding sections for decomposing lime and barytes. To the metallic basis of it he gave the name of *strontium*.

This metal is white, solid, much heavier than water, and

Strontium.

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* Vol. ii. 189.

† Vol. i. 99. See also Klaproth's Beitrage, i. 260, and Jour. de Min. No. v. p. 61.

‡ Ann. de Chim. xxi. 113 and 276. Jour. de Min. An. vi. 3.

§ Pelletier, Ibid. xxi. 120.

bears a close resemblance to *barium* in its properties. When exposed to the air, or when thrown into water, it rapidly absorbs oxygen, and is converted into strontian.*

Oxides.   II. Strontium combines with two proportions of oxygen, and forms two oxides; namely, strontian and peroxide of strontium, for the knowledge of which we are indebted to Thenard.

Strontian.   1. Strontian prepared by the process already described is a porous mass of a grayish white colour. It has an acrid taste, and converts vegetable blues to green.

When water is sprinkled on strontian it is slacked, becomes hot, and falls to powder exactly like barytes; but it is not so soluble in water as that earth. One hundred and sixty-two parts of water, at the temperature of 60°, dissolve nearly one part of strontian. The solution, known by the name of *strontian water*, is clear and transparent, and converts vegetable blues to a green. Hot water dissolves it in much larger quantities; and as it cools, the strontian is deposited in colourless transparent crystals. These are in the form of thin quadrangular plates, generally parallelograms, the largest of which seldom exceeds one-fourth of an inch in length. Sometimes their edges are plain, but they oftener consist of two facets, meeting together, and forming an angle like the roof of a house. These crystals generally adhere to each other in such a manner as to form a thin plate of an inch or more in length and half an inch in breadth. Sometimes they assume a cubic form. They contain about 68 parts in 100 of water. They are soluble in 51·4 parts of water at the temperature of 60°. Boiling water dissolves nearly half its weight of them. When exposed to the air, they lose their water, attract carbonic acid, and fall into powder.†

Mr. Brooke has ascertained that the primary form of the crystals of this hydrate is a right square prism.‡ Most commonly the prism is terminated by a four-sided pyramid, usually truncated at its extremity. The face of the prism makes, with the corresponding face of the pyramid, an angle of 132° 12'.

It appears from the experiments of Bucholz, that strontian obtained by heating these crystals has the property of fusing at a red heat, while strontian from the nitrate is destitute of

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* Davy's Electro-chemical Researches into the Decomposition of the Earths, &c.; Phil. Trans. 1808.

† Hope, Edin. Trans. iv. 44.

‡ Annals of Philosophy (2d series), vii. 287.

that property.*   Hence it is obvious that the first is a *hydrate*
of strontian.   It is, no doubt, composed of 1 atom strontian +
1 atom water, or by weight of

Strontian	.	.	6·500	. .	100
Water	.	.	1·125	•. .	17·3

The crystals of strontian appear from Dr. Hope's analysis
above stated, to be composed of 1 atom strontian + 12 atoms
water, or by weight of

Strontian	.	.	6·5	. .	100
Water	.	.	13·5	. .	207·69

Strontian has the property of tinging flame of a beautiful
red colour; a property discovered by Dr. Ash in 1787.   The
experiment may be made by putting a little of the salt com-
posed of nitric acid and strontian into the wick of a lighted
candle ;† or by setting fire to alcohol, holding muriate of stron-
tian in solution.   In both cases the flame is of a lively purple.
In this respect it differs from barytes, which when tried in
the same way is found to communicate a bluish yellow tinge to
the flame.‡

I have shown that the atomic weight of strontian is 6·5.§
And from the action of chlorine on it, first observed by Davy,
it is clear that it is a compound of 1 atom strontium and 1 atom
oxygen.   Hence its constituents are

1 atom strontium	.	.	5·5•
1 atom oxygen	.	. .	1
			——
			6·5

and the atomic weight of strontium is 5·5.

2. *Peroxide of strontium* is obtained in bright scales when
strontian water is mixed with deutoxide of hydrogen.   Its
properties are similar to those of peroxide of barium; but it
may be more easily dried.   According to the analysis of
Thenard, it is composed of

1 atom strontium	.	.	5·5
2 atoms oxygen	.	.	2
			——
			7·5

III. Chloride of strontium is easily formed by heating stron-
tian in chlorine gas, or by dissolving it in muriatic acid and

* Gehlen's Journal für de Chemie, Physick, und Mineralogie, iv. 664.
† Vauquelin, Jour. de Min. An. vi. 10.
‡ Pelletier, Ann. de Chim. xxi. 137.
§ Annals of Philosophy (2d series), i. 5.

crystallizing.　As it possesses the characters of a salt, it will come to be described in a subsequent part of this work.　For the same reason the bromide and iodide will be reserved till we come to the salts, of which they constitute species.

IV. The phosphuret and sulphuret of strontium resemble those of barium so closely, that a detailed description of them seems unnecessary.

Nothing is known respecting the combination of strontium with hydrogen, azote, carbon, boron, silicon, or selenium, or of the alloys which it may form with the metals.

Barytes and strontian resemble each other in their properties as closely as potash and soda : hence, like these two alkalies, they were for some time confounded.　It is in their combination with acids that the most striking differences between these two earths are to be observed.　The best way of separating them, when mixed together and dissolved in an acid, is, according to Berzelius, to add a quantity of fluosilicic acid to the solution.　The barytes is thrown down, but the strontian remains in solution till the whole be reduced by evaporation to the consistence of a magma.

SECTION VI.—OF CALCIUM.

Lime has been known from the earliest ages.　The ancients employed it in medicine ; it was the chief ingredient in their mortar ; and they used it as a manure to fertilize their fields.

Lime abounds in most parts of the world, or perhaps I should rather say, that there is no part of the world where it does not exist.　It is found purest in limestone, and marble, and chalk. None of these substances, however, is, strictly speaking, lime ; but they are all capable of becoming lime by a well-known process, by keeping them for some time in a white heat : this process is called *the burning of lime.*　The product, which in common language is denominated *quicklime,* is the substance known in chemistry by the name of *lime.*

How obtained. 1. Lime may be obtained pure by burning those crystallized limestones, called *calcareous spars,* which are perfectly white and transparent, and also by burning some pure white marbles. It may be procured also in a state of purity by dissolving oyster-shells in muriatic acid, filtering the solution, mixing it with ammonia as long as a white powder continues to fall, and filtering again.　The liquid is now to be mixed with a solution of carbonate of soda ; the powder which falls, being washed and dried, and heated violently in a platinum crucible, is pure lime.

2. Pure lime is of a white colour, moderately hard, but easily reduced to a powder.

It has a hot burning taste, and in some measure corrodes and destroys the texture of those animal bodies to which it is applied. Its specific gravity is 3·08.* It tinges vegetable blues green, and at last converts them to yellow.

With respect to the composition of lime nothing better than conjecture was advanced on the subject, till Davy's great discovery of the bases of potash and soda. This naturally led him to the idea that lime and the other earthy bodies possessing properties similar to lime, were likewise compounds of oxygen and particular metals.

He accordingly exposed them in various states to the action of a galvanic battery, and found reason to conclude that his opinion of their nature was correct, though he found it much more difficult to decompose them and obtain their bases, than it had been to obtain potassium and sodium by similar processes. When acted upon under naphtha they were not distinctly decomposed. When fused with an excess of potash, and acted upon in that state, the results were rather more distinct, metallic substances appeared less fusible than potassium, which burnt the instant after they were formed, and produced a mixture of potash and the earth employed. When the earths were exposed to the action of electricity, mixed with the oxides of mercury, tin, lead, or silver, amalgams were produced, which exhibited properties indicating unequivocally that they were mixtures of the base of the earth employed and of the base of the metallic oxide mixed with it. But the quantity of amalgam obtained was too minute to admit of an accurate examination. While Sir H. Davy was engaged in these experiments, he received a letter from Professor Berzelius of Stockholm, informing him that he and Dr. Pontin had succeeded in decomposing barytes and lime, by negatively electrifying mercury in contact with them. Davy immediately repeated this happy experiment, and succeeded completely in obtaining amalgams of the base of the earth employed.

To procure these amalgams in sufficient quantity for distilling off the mercury, and obtaining the base of the earth pure, Davy combined his own previous method with that of Berzelius and Pontin. The earth was slightly moistened, mixed with one-third of red oxide of mercury, and placed upon a plate of

* Roger and Dumas, Annals of Philosophy, iii. 392.

platinum connected with the positive end of the battery.   A cavity was made in the earthy mixture, a globule of about 60 grains of mercury put into it, and this globule connected with the negative end of the battery by a platinum wire.   The amalgams obtained in this way were distilled in glass tubes filled with the vapour of naphtha. The greater part of the mercury was easily driven off, but it was extremely difficult to separate the whole. The globule that remained behind was in all cases white like silver, solid, and extremely combustible. When exposed to the air it absorbed oxygen, and regenerated the earth from which it was obtained in a few minutes.

Properties.   The metallic basis of lime Davy has called *calcium.* He did not succeed in investigating its properties.   It is white like silver, solid, and probably 4 or 8 times heavier than water. When heated in the open air it burns brilliantly, and quick-lime is produced.*

Oxides.   II. Calcium, so far as is known at present, unites only with two proportions of oxygen, and forms two oxides, known by the name of *lime* and *peroxide of calcium.*

1. Lime cannot be fused by the most violent heat of our furnaces. But Dr. Clarke has succeeded in fusing it by means of a blow-pipe, consisting of a jet of two volumes hydrogen, and one volume oxygen gases, issuing with violence from the point of a capillary tube. It is converted into a brilliant limpid glass, and during the fusion a beautiful lambent flame of an amethystine hue makes its appearance.†

If water be poured on newly-burnt lime, it swells and falls to pieces, and is soon reduced to a very fine powder.   In the mean time, so much heat is produced, that part of the water flies off in vapour. If the quantity of lime slacked (as this process is termed) be great, the heat produced is sufficient to set fire to combustibles.   In this manner, vessels loaded with lime have sometimes been burnt.   When great quantities of lime are slacked in a dark place, not only heat but light also is emitted, as Mr. Pelletier has observed.‡   When slacked lime is weighed, it is found to be heavier than it was before.   This additional weight is owing to the combination of part of the water with the lime; which water may be separated again by the application of a red heat; and by this process the lime becomes just what it was before being slacked.§   Hence the

* Phil. Trans. 1808, p. 333.
† Journal of the Royal Institution, ii. 113.
‡ Jour. de Phys. tom. 22.   § Dr. Black.

reason of the heat evolved during the slacking of lime. Part of the water combines with the lime, and thus becomes solid; of course it parts with its caloric of fluidity, and probably also with a considerable quantity of caloric which exists in water even when in the state of ice : for when two parts of lime and one part of ice (each at 32°) are mixed, they combine rapidly, and their temperature is elevated to 212°. The elevation of temperature during the slacking of barytes and strontian is owing to the same cause.

Slacked lime or *hydrate of lime* is no doubt a compound of 1 atom lime + 1 atom water, or it is composed by weight of

Hydrated lime.

| Lime | . | . | 3·5 | . | . | . | 100 |
| Water | . | . | 1·125 | . | . | | 32·15 |

Mr. Dalton* found slacked lime well dried in a moderate heat composed of

| Lime | . | . | 100 |
| Water | . | . | 33·3 |

The result of Lavoisier's experiments† gave

| Lime | . | . | 100 |
| Water | . | . | 28·7 |

Those of Berzelius

| Lime | . | . | 100 |
| Water | . | . | 32·17 |

which is very near the theoretical result.

Gay-Lussac has hit upon a very ingenious method of crys- Crystals. tallizing lime. He dissolves it in water, and places the lime-water formed in an open vessel under the exhausted receiver of an air-pump, along with a quantity of concentrated sulphuric acid in another open vessel. When the acid has become too weak in consequence of the evaporation of the lime water it is withdrawn, and new concentrated acid substituted in its place. By degrees the lime is deposited in small crystals, which exhibit the form of fragments of six-sided prisms.‡

By my trials 758 grains of cold water dissolve 1 grain of Lime water. lime. According to Mr. Dalton, who has examined this subject with attention, cold water dissolves more lime than hot water. The following table shows the solubility of lime and its hydrate in water of different temperatures, according to his experiments.§

* New System of Chemical Philosophy, i. 87.
† Lavoisier's Essays, translated by Henry, p. 280.
‡ Ann. de Chim. et Phys. i. 334.
§ New System of Chemical Philosophy, ii. 510.

Chap. III.

1 Part of water at	Takes up of lime	Takes up of dry hydrate
60°	$\frac{1}{78}$	$\frac{1}{384}$
130	$\frac{1}{972}$	$\frac{1}{729}$
212	$\frac{1}{1270}$	$\frac{1}{952}$

Lime water, as this solution is called, is limpid, has an acrid taste, and changes vegetable blue colours to green. It is usually formed by throwing a quantity of lime in powder into pure water, allowing it to remain for some time in a close vessel, and then decanting the transparent solution from the undissolved lime. When lime-water is exposed to the air, a stony crust soon forms on its surface composed of carbonate of lime; when this crust is broken it falls to the bottom, and another succeeds it; and in this manner the whole of the lime is soon precipitated, by absorbing carbonic acid from the air.

The smell perceived during the slacking of lime is owing to a part of that earth being elevated along with the vapour of the water; as evidently appears from this circumstance, that vegetable blues exposed to this vapour are converted into green.

Burning of lime explained.   Limestone and chalk, though they are capable of being converted into lime by *burning*, possess hardly any of the properties of that active substance. They are tasteless, scarcely soluble in water and do not perceptibly act on animal bodies. Now, to what are the new properties of lime owing? What alteration does it undergo in the fire?

It had been long known, that limestone loses a good deal of weight by being burned or *calcined*. It was natural to suppose, therefore, that something is separated from it during calcination. Accordingly, Van Helmont, Ludovicus, and Macquer, made experiments in succession, in order to discover what that *something* is; and they concluded from them that it is *pure water*, which the lime recovers again when exposed to the atmosphere. As the new properties of lime could hardly be ascribed to this loss, but to some other cause, Stahl's opinion, like all the other chemical theories of that wonderful man, was generally acceded to. He supposed that the new properties which lime acquired by calcination are owing entirely to the more minute division of its particles by the action of the fire. Boyle indeed had endeavoured to prove that these properties are owing to the *fixation of fire* in the lime; a theory which was embraced by Newton and illustrated by Hales, and which Meyer new modelled, and explained with so much ingenuity and acuteness as to draw the attention of the most distinguished chemists. But while Meyer was thus employed

in Germany, Dr. Black of Edinburgh published, in 1756, those celebrated experiments which form so brilliant an era in the history of chemistry.

He first ascertained, that the quantity of water separated from limestone during its calcination is not nearly equal to the weight which it loses. He concluded in consequence, that it must have lost something else than mere water. What this could be, he was at first at a loss to conceive; but recollecting that Dr. Hales had proved that limestone, during its solution in acids, emits a great quantity of *air*, he conjectured that *this* might probably be what is lost during calcination. He calcined it accordingly, and applied a pneumatic apparatus to receive the product. He found his conjecture verified; and that the *air* and the *water* which separated from the lime were together precisely equal to the loss of weight which it had sustained. Lime therefore owes its new properties to the loss of *air;* and limestone differs from lime merely in being combined with a certain quantity of *air!* for he found that, by restoring again the same quantity of *air* to lime, it was converted into limestone. This air, because it existed in lime in a fixed state, he called *fixed air*. It was afterwards examined by Dr. Priestley and other philosophers; found to possess peculiar properties, and to be that species of gas now known by the name of *carbonic acid gas*. Lime then is the simple substance, and limestone is composed of carbonic acid and lime. Heat separates the carbonic acid and leaves the lime in a state of purity.

When lime is exposed to the open air, it gradually attracts moisture, and falls to powder; after which it soon becomes saturated with carbonic acid, and is again converted into carbonate of lime or unburnt limestone.

My experiments, I conceive, leave no doubt that the atomic weight of lime is 3·5.* From the decomposition of lime by chlorine, it is pretty evident that it is a compound of one atom of base and 1 atom of oxygen. Hence its constituents must be

Calcium	.	.	2·5
Oxygen	.	.	1·0
			——
			3·5

and the atomic weight of calcium must be 2·5.

Lime is applied to a great variety of uses. It serves as a manure to land; it is employed as an antacid in medicine; it

* Annals of Philosophy (2d Series), i. 6.

is an excellent building stone, and it constitutes the essential ingredient in mortar.

Mortar.   Mortar is composed of quicklime and sand reduced to a paste with water. When dry it becomes as hard as stone, and as durable; and adhering very strongly to the surfaces of the stones which it. is employed to cement, the whole wall becomes in fact nothing else than one single stone. But this effect is produced very imperfectly unless the mortar be very well prepared.

The lime ought to be pure, completely free from carbonic acid, and in the state of a very fine powder: the sand should be free from clay, and partly in the state of fine sand, partly in that of. gravel: the water should be pure ; and if previously saturated with lime, so much the better. The best proportions, according to the experiments of Dr. Higgins, are 3 parts of fine sand, 4 parts of coarser sand, 1 part of quicklime recently slacked, and as little water as possible.

The stony consistence which mortar acquires is owing, partly to the absorption of carbonic acid, but principally to the combination of part of the water with the lime. This last circumstance is the reason, that if to common mortar one-fourth part of lime, reduced to powder without being slacked, be added, the mortar when dry acquires much greater solidity than it otherwise would do. This was first proposed by Loriot ;* and a number of experiments were afterwards made by Morveau.† The proportions which this philosopher found to answer best are the following :

Fine sand	0·3
Cement of well baked bricks	0·3
Slacked lime	0·2
Unslacked lime	0·2
	1·0

The same advantages may be attained by using as little water as possible in slacking the lime. This was first pointed out by La Faye.‡

Higgins found that the addition of burnt bones improved mortar by giving it tenacity, and rendering it less apt to crack in drying; but they ought never to exceed one-fourth of the lime employed.

When a little clay is added to mortar, it acquires the important property of hardening under water; so that it may be

employed in constructing those edifices which are constantly
exposed to the action of water. Limestone is found not un-
frequently mixed with clay: and in that case it becomes brown
by calcination, instead of white. These native limestones are
employed for making *water mortar ;* but good water mortar
may be made by the following process, first proposed by Mor-
veau: Mix together 4 parts of blue clay, 6 parts of black
oxide of manganese, and 90 parts of limestone, all in powder.
Calcine this mixture to expel the carbonic acid, mix it with
60 parts of sand, and form it into mortar with a sufficient
quantity of water.*

The best mortar for resisting water is made by mixing with
lime puzzolano, a volcanic sand brought from Italy. Morveau
informs us that *basaltes,* which is very common in this country,
may be substituted for puzzolano. It must be heated in a fur-
nace, thrown while red-hot into water, and then passed through
a sieve to reduce it to the proper size.†

I find by analyzing Arden lime, near Glasgow, which con- Water mor-
stitutes an excellent water mortar, that it contains a consider- tar.
able quantity of silica, and that when the lime is burnt the
silica enters into chemical combination with it. For when the
lime is dissolved in muriatic acid and the solution sufficiently
concentrated, the silica gelatinizes. It seems to be this silicate
of lime which gives the mortar the property of setting under
water.

2. Peroxide of lime was discovered by M. Thenard. He Peroxide.
obtained it by letting fall, drop by drop, limewater into deut-
oxide of hydrogen. Small brilliant scales fall, which constitute
the peroxide of lime. It undergoes spontaneous decomposition
when kept under water, and cannot be dried in vacuo without
losing its excess of oxygen. It is composed, according to
Thenard, of

1 atom calcium	2·5
2 atoms oxygen	·2
	4·5

and its atomic weight is 4·5.

III. Chloride of calcium is easily formed by passing a cur- Chloride.
rent of dry chlorine gas, over lime previously heated to red-
ness. The oxygen of the lime is disengaged and chloride of
calcium formed, as was first shown by Sir H. Davy. It may

* Ann. de Chim. xxxvii. 259. † Ibid. xxxvii. 262.

Chap. III.　be obtained also by simply dissolving lime in muriatic acid, and crystalizing the solution. It possesses the characters of a salt, and will therefore be described in the second volume of this work.

The bromide and iodide of calcium are also salts, and will be described hereafter.

Chloride of lime.　But chlorine has the property of combining with hydrate of lime, and of forming a compound which may be called *chloride of lime*. It was first made by Messrs. Tennant and Macintosh, of Glasgow, and has now become a most important article of commerce, under the name of bleaching powder. It is made by exposing slacked lime, in fine powder, in a chamber filled with chlorine gas, till it refuse to absorb any more. Some years ago, when examined by Mr. Dalton, it was a compound of 1 atom chlorine and 2 atoms lime; but of late years the quality has been so much improved that it is now (as manufactured in Glasgow,) a compound of

1 atom chlorine	.	4·5
1 atom lime	.	3·5
		——
		8

at least very nearly, for it dissolves in water leaving only a very slight residue, consisting chiefly of impurities in the lime, with a very little lime. This chloride has an exceedingly hot taste, and dissolves readily in water. Its bleaching properties are so considerable that it is always used in this country for the bleaching of cotton cloth, which is never now exposed to the sun upon grass as formerly. When exposed to the air it remains for some hours unaltered; but at last begins to absorb moisture, and flows ultimately into a liquid which consists of a solution of chloride of calcium. It has a peculiar smell, not quite the same, but analogous to that of chlorine. When heated it gives out oxygen gas mixed at first with a little chlorine.

How tested.　The usual mode of determining the strength of bleaching powder, is to ascertain how much solution of indigo in sulphuric acid is discoloured by a given weight of the powder previously dissolved in water. But this method, notwithstanding the ameliorations introduced into it by Gay-Lussac, is, I think liable to considerable uncertainty. I have been in the habit myself of testing the bleaching powder by means of muriate of manganese, which it has the property of throwing down in the state of teroxide of manganese, and the weight of teroxide obtained measures the strength of the bleaching powder. The

only precaution necessary, is to take care that the solution of the bleaching powder contains no free lime, which is almost always the case. This excess must be exactly neutralized by muriatic acid, and care must be taken not to add too much, otherwise the result will not be exact. • This makes the process rather unfit for common bleachers; though it has been recommended by Morin as preferable to the indigo test.* Mr. Dalton proposed the addition of a solution of bleaching powder to a solution of protosulphate of iron, till the smell of chlorine begins to be perceived. And my friend Mr. Crum, one of the most extensive bleachers in the neighbourhood of Glasgow, and an excellent practical chemist, informs me that he always employs this method, and finds it both exact and delicate.

With respect to the nature of bleaching powder, two opinions at present divide the chemical world. The first and the most common one is, that it is a compound of chlorine and lime. The second is that advanced by Berzelius; which must at present be viewed in the light of an ingenious and plausible conjecture. According to him chlorine and oxygen are capable of forming an acid containing less oxygen than chloric acid, and which, therefore, he calls *chlorous acid*. We do not yet know the exact composition of this acid, but we may suppose it (for the sake of explaining the nature of the chloride), a compound of 1 atom chlorine and 3 atoms oxygen. When the chlorine comes in contact with the lime, three-fourths of the lime give out their oxygen to 1 atom of chlorine, and convert it into chlorous acid. This atom of chlorous acid unites to the remaining fourth of the lime, and forms with it chlorite of lime, while the three atoms of calcium evolved unite to chlorine, and form chloride of calcium. According to this view of the subject bleaching powder is a mixture of

<div align="center">

3 atoms chloride of calcium = 21
1 atom chlorite of lime   = 11

</div>

So that nearly two-thirds of it is chloride of calcium, and little more than one-third chlorite of lime. It is to the chlorite of lime that the bleaching powers of the liquid are owing. Its oxygen being loosely combined is given out, and acting on the colouring matter of the cloth produces its bleaching effects.†

This opinion of Berzelius is founded chiefly upon the properties of the combination of chlorine and potash. It yields,

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* Ann. de Chim. et de Phys. xxxvii. 142.
† Poggendorf's Annalen. xii. 529.

when evaporated, a peculiar salt which dissolves in water, and possesses bleaching properties. Faraday obtained a similar salt when the disinfecting liquid of Labaraque, formed by combining a determinate quantity of chlorine gas with solution of carbonate of soda is evaporated to dryness. No chlorine is given off during the evaporation, and the salt possesses peculiar properties, and has bleaching powers. These facts undoubtedly deserve the attention of chemists, and are sufficient to satisfy us that the nature of this combination has not yet been accurately determined. It is rather inconsistent, however, with the opinion of Berzelius, that bleaching powder does not attract moisture from the atmosphere nearly so fast as we would expect, from a substance containing so great a proportion of chloride of calcium, as his hypothesis would indicate. It is also remarkable that chlorine gas is evolved when sulphuric acid is dropt into a solution of bleaching powder. This does not happen when we pour that acid into a solution of chlorate of potash. I say nothing respecting the quateroxide of chlorine of Davy and Count Von Stadion, because the analysis of that oxide is probably inaccurate. Yet it would require to be proved so, before the existence of a chlorous acid couldbe admitted. The investigation of the nature of this substance is environed with many difficulties; but it is highly worthy the attention of chemists.

Phosphuret. IV. Phosphuret of calcium may be formed precisely in the same way as phosphuret of barium. This phosphuret was first formed by Mr. Smithson Tennant. Phosphuret of calcium has a deep brown colour, and is moulded into the shape of the tube. It falls to pieces in the air. It is insoluble in water; but it has the property of decomposing that liquid. Phosphuretted hydrogen mixed with hydrogen gas is emitted, which takes fire as soon as it comes to the surface of the water.

This phosphuret has not yet been analyzed; but it is exceedingly probable that like phosphuret of barium it is a compound of

1 atom phosphate of lime	. . .	8
$2\frac{1}{2}$ atoms biphosphuret of calcium	. .	11·25

V. Sulphur and calcium unite in various proportions. Three only of these sulphurets have been hitherto examined.

Sulphuret. 1. Sulphuret of calcium is obtained when we mix anhydrous sulphate of lime in powder with about $\frac{1}{5}$th of its weight of charcoal powder, and expose the mixture in a covered crucible to a white heat for a couple of hours. Its colour is reddish.

It dissolves imperfectly in water, but with great ease in muriatic acid, while a great quantity of sulphuretted hydrogen gas is evolved. On this account Berthier recommends this process as the easiest and cheapest for procuring sulphuretted hydrogen gas.* It may be obtained (but mixed with sulphate of lime), also when we heat a mixture of lime and sulphur cautiously to redness in a covered crucible. When thus prepared it is a pyrophorus, and is known under the name of phosphorus of Canton. This sulphuret is a compound of

1 atom sulphur . .	2
1 atom calcium . .	2·5
	——
	4·5

45 grains of it, when dissolved in muriatic acid, give out 21¼ grains of sulphuretted hydrogen gas.

2. *Bisulphuret of calcium* was discovered by Mr. Herschell. Bisulphuret. It may be obtained by boiling a mixture of slacked lime, sulphur, and water, and allowing the liquid to cool slowly before it be perfectly saturated with sulphur. Yellow coloured crystals separate, which are more abundant when allowed to form over the excess of lime and sulphur contained in the liquid. These crystals require 400 times their weight of water at 60° to dissolve them. But they are more soluble in boiling water. Their water of crystallization amounts to 43·45 per cent. of their weight. They consist of

2 atoms sulphur . .	4
1 atom calcium . .	2·5
	——
	6·5

It is obvious that the crystals consist of

1 atom bisulphuret of calcium . .	6·5
4½ atoms water	5·0625
	————
	11·5625

3. When sulphuret of calcium is boiled in water with sul- Quintosul-
phuret. phur, till no more sulphur can be dissolved, we form a persulphuret of calcium composed of

5 atoms sulphur . .	10
1 atom calcium . .	2·5
	——
	12·5

* Ann. de Chim. et de Phys. xxiv. 275.

This persulphuret was proposed many years ago in Ireland as a substitute for potash ley in bleaching. Whether it be employed in any part of Ireland for this purpose I do not know. But the bleachers in this part of the country never make any use of it.

VI. Nothing is known respecting the combination of selenium and calcium, and scarcely any experiments have been made on the alloys which calcium may be capable of forming with the different metals.

<div align="center">SECTION VII.—OF MAGNESIUM.</div>

About the beginning of the eighteenth century, a Roman canon exposed a white powder to sale at Rome as a cure for all diseases. This powder he called *magnesia alba.* He kept the manner of preparing it a profound secret; but in 1707 Valentini informed the public that it might be obtained by calcining the lixivium which remains after the preparation of nitre;* and two years after, Slevogt discovered that it might be precipitated by potash from the mother ley† of nitre.‡ This powder was generally supposed to be *lime,* till Frederic Hoffman observed that it formed very different combinations with other bodies.§ But little was known concerning its nature, and it was even confounded with lime by most chemists, till Dr. Black made his celebrated experiments on it in 1755. Margraff published a dissertation on it in 1759,‖ and Bergman another in 1775, in which he collected the observations of these two philosophers, and which he enriched also with many additions of his own.¶ Butini, of Geneva, likewise published a valuable dissertation, on it in 1779.

Magnesia is never found native in a state of purity, but it may be prepared in the following manner: *Sulphate of magnesia,* a salt composed of this earth and sulphuric acid, exists in sea-water, and in many springs, particularly in some about Epsom; from which circumstance it was formerly called *Epsom salt.* This salt is to be dissolved in boiling water, and a boiling

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* De Magnesia Alba.

† The mother ley is the liquid that remains after as much as possible of any salt has been obtained from it. Common salt, for instance, is obtained by evaporating sea-water. After as much salt has been extracted from a quantity of sea-water as will crystallize, there is still a portion of liquid remaining. This portion is the mother ley.

‡ Diss. de Magnesia Alba.

§ Obs. Phys. Chim. 1722, pp. 105 and 177.   ‖ Opus. ii. 20.

¶ Opus. i. 365.

solution of carbonate of soda added. The magnesia is precipi-
tated in the state of a carbonate. It is then to be washed with
a sufficient quantity of water, dried, and heated to redness.

Magnesia, thus obtained, is a very soft white powder, which
has very little taste, and is totally destitute of smell. Its specific
gravity is about 2·3.* It converts vegetable blues to green.

Davy, after his decomposition of potash and soda, was
naturally led to consider magnesia also to be a metallic oxide.
He succeeded in decomposing it by the same process by which
he decomposed the other alkaline earths. When moistened
magnesia is exposed to the action of galvanism in contact with
mercury, the earth is reduced, and its base amalgamated with
mercury much more slowly than the other alkaline earths;
owing probably to its insolubility in water. The process
succeeds much more rapidly when moistened sulphate of mag-
nesia is substituted for the pure earth. To the base of magnesia,
thus obtained, Davy gave the name of *magnesium.*

Magnesium is a white solid metal, having the appearance of
silver; sinks rapidly in water, and of course is considerably
heavier than that liquid. When the amalgam of magnesium
is distilled in a glass tube filled with the vapour of naphtha,
the metal appears to act upon the glass before the whole of the
mercury is separated from it. Of course it is difficult to obtain
it in a state of purity. When exposed to the air it rapidly
absorbs oxygen, and is converted into magnesia. It decom-
poses water, separating the hydrogen, and combining with the
oxygen; but not nearly so rapidly as the other metals obtained
from the alkaline earths; owing, doubtless, to the insolubility
of the magnesia in water. But when the water is acidulated
with sulphuric acid, the decomposition of water and the forma-
tion of magnesia goes on with great rapidity.

M. Bussey has lately announced that by passing the vapour
of potassium over the chloride of magnesium, heated to redness
in a porcelain tube, the magnesium is disengaged and may be
collected on a filter. It is in the state of brown flocks, which
when rubbed in an agate mortar assume the metallic lustre,
and resemble lead in appearance. According to Bussey, mag-
nesium is not attacked by dilute nitric acid, but it is dissolved
by muriatic acid. When heated before the blow-pipe it takes

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* Kirwan's Miner. i. 8.
† Davy's Electro-chemical Researches on the Decomposition of the
Earths, &c. Phil. Trans. 1808.

fire, and is converted into magnesia.* I am not aware that this experiment of Bussey has been verified by any other chemist.

II. We are at present acquainted with only one oxide of magnesium; namely, *magnesia.*

Magnesia.

Magnesia occurs in considerable quantity in the state of anhydrous carbonate. A whole range of low hills consisting of it is said to exist in India. In serpentine rocks it occurs in the state of a hydrate, composed of 1 atom magnesia and 1 atom water. Fine specimens of this hydrate occur at Swinaness in Unst, one of the Shetland islands, where it was discovered by Dr. Hibbert, traversing the serpentine, in veins. It occurs also at Hoboken in New Jersey. It occurs also in the state of a hydro-carbonate, a silicate, bisilicate, and tersilicate, and enters also as a constituent into a considerable number of minerals, in which it exists in the state of double or triple salt.

Magnesia is not melted by the strongest heat which it has been posssible to apply; but Mr. Darcet observed that, in a very high temperature, it became somewhat agglutinated. When formed into a cake with water, and then exposed to a violent heat, the water is gradually driven off, and the magnesia contracts in its dimensions; at the same time, as Mr. Tingry informs us, it acquires the property of shining in the dark when rubbed upon a hot iron plate. Dr. Clarke, by a stream of oxygen and hydrogen gases, fused it with great difficulty into a white enamel.

Butini of Geneva showed, many years ago, that carbonate of magnesia is soluble in water, and more soluble in cold than in hot water. The subject was taken up about ten years ago by Dr. Fife of Edinburgh, who ascertained that at 212°, 1 part of magnesia requires 36,000 parts of water to dissolve it, but at the temperature of 60°, 1 part of magnesia requires for solution only 5760 parts of water. Carbonate of magnesia is soluble in 2493 parts of cold, and requires 9000 parts of boiling hot water to dissolve it.†

How detected.

1. Caustic magnesia does not solidify water like barytes, strontian, and lime; hence it does not become hot when water is thrown on it. Neither does it absorb carbonic acid gas from the atmosphere. It has a strong affinity for silica. Dr. Wollaston first pointed out a method of detecting the presence of the minutest quantity of magnesia in minerals. His method

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* Poggendorf's Annals, xiv. 181.   † Edin. Jour. v. 305.

is as follows: Dissolve in a watch glass a minute fragment of the mineral.* Render the solution neutral by cautious evaporation; then while hot add a little oxalate of ammonia to precipitate any lime which it may contain. Let the precipitate fall, and take a few drops of the clear liquid and put them on a slip of window-glass. Add a drop or two of bicarbonate of ammonia, and afterwards a drop or two of biphosphate of ammonia. Then draw a little of the clear solution to one side with a glass rod, and trace any letters or lines across it with a glass rod. On exposing it to a gentle heat, white traces will be perceived wherever the rod was applied.

It has been ascertained that sulphate of magnesia (abstracting the water) is a compound of

Sulphuric acid	. .	5
Magnesia	. .	2·5
		——
		7·5

Now the salt is neutral, and consequently the atomic weight of magnesia is 2·5. From Davy's experiments, it is clear that magnesia is a compound of

1 atom magnesium	. .	1·5
1 atom oxygen	. .	1
		——
		2·5

Consequently the atomic weight of magnesium is 1·5.

III. When magnesia is heated in chlorine gas it parts with its oxygen, and is converted into chloride of magnesium. As this chloride possesses the characters of a salt, the account of it is deferred to the second volume of this work. For the same reason the bromide and iodide of magnesium will occupy our attention afterwards.

IV. Nothing is known respecting any compounds which magnesium may be capable of forming with hydrogen, azote, carbon, boron, silicon, or phosphorus.

V. No accurate experiments have hitherto been made upon the formation of the sulphuret of magnesium. Berthier, who formed so many sulphurets by heating sulphates with charcoal, does not appear to have tried the sulphate of magnesia. If we mix hydrate of magnesia with water, and pass a current of sulphuretted hydrogen gas through the solution, as long as that

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* If it is not soluble it must be rendered so by previous fusion with carbonate of soda.

gas continues to be absorbed, filter the solution, and boil it in a retort, the uncombined sulphuretted hydrogen gas is driven off, and a white mucilaginous matter falls down, which is a sulphuret of magnesium. The same sulphuret is obtained when hydrosulphuret of potash is mixed with a solution of sulphate of magnesia.

When caustic magnesia and sulphur are boiled in water, a sulphuret of magnesium is gradually dissolved. But the process is tedious, and yields a very small quantity of product. We do not succeed in forming a sulphuret when we heat magnesia and sulphur together in a crucible. The sulphur flies off and leaves the magnesia unaltered.

VI. Nothing is known respecting the seleniet of magnesium or of the alloys which it may be capable of forming with the metals.

THE OXIDES of these seven metals constitute the most powerful alkaline bodies. They all combine readily with acids, and form *salts*. These salts have been more completely investigated than any others. An account of them will be given in a subsequent part of this work. All the chlorides, bromides, and iodides of these bodies are also salts. The order of the affinity of these bodies for acids is as follows:

Barytes,	Lime,
Strontian,	Lithia?
Potash,	Magnesia.
Soda,	

But to this order there are some exceptions. For example, lime unites to oxalic acid in preference to any of the other bases, when they are all in solution together.

FAMILY II.—EARTHY BASES.

The six bodies belonging to this family, when united to oxygen, form white, tasteless powders, insoluble in water, and formerly distinguished by the name of *earths*. It is now known that there is no true distinction between *earths* and *metallic oxides*. But the six bases included in this family have so many properties in common, that it is proper to consider them together. And for want of a better name I have distinguished the family by the term *Earthy*, which was formerly applied to the oxides of these bases.

SECTION I.——OF ALUMINUM.

Alum is a salt which was known many centuries ago, and employed in dyeing, though its component parts were unknown. The alchymists discovered that it is composed of sulphuric acid and an earth ; but the nature of this earth was long unknown. Stahl and Neuman supposed it to be lime; but in 1728 Geoffroy, junior, proved this to be a mistake, and demonstrated, that the earth of alum constitutes a part of clay.* In 1754, Margraff showed that the basis of alum is an earth of a peculiar nature, different from every other ; an earth which is an essential ingredient in clays, and gives them their peculiar properties.† Hence this earth was called *argil;* but Morveau afterwards gave it the name of *alumina,* because it is obtained in the state of greatest purity from alum. The properties of alumina were still farther examined by Macquer in 1758 and 1762,‡ by Bergman in 1767 and 1771,§ and by Scheele in 1776 ;‖ not to mention several other chemists who have contributed to the complete investigation of this substance. A very ingenious treatise on it was published by Saussure, junior, in 1801.¶

Alumina may be obtained by the following process : Dissolve alum in water, and add to the solution an excess of carbonate of soda, and digest the mixture for some time to deprive the precipitated alumina of all the sulphuric acid with which it was united. Wash the precipitate with a sufficient quantity of water, dissolve it in muriatic acid, and precipitate the alumina from this solution by carbonate of ammonia. Digest the precipitate for some time in carbonate of ammonia. Then wash it and dry it. Pure alumina is easily obtained from ammoniacal alum, simply by exposing it to a strong red heat.

Alumina thus obtained assumes two very different appearances according to the way in which the precipitation has been conducted. If the earthy salt be dissolved in as little water as possible, the alumina has the appearance of a white earth, light, friable, very spongy, and attaching itself strongly to the tongue. In this state Saussure distinguishes it by the name of *spongy alumina.*

But if the salt has been dissolved in a great quantity of water, the alumina is obtained in a brittle transparent yellow coloured mass, splitting in pieces like roll sulphur when held in the

* Mem. Par. 1728, p. 303.
† Mem. Berlin, 1754 and 1759, Margraff, ii. 1.   ‡ Mem. Paris.
§ Bergman, i. 287, and v. 71.
‖ Scheele, i. 191, French Transl.   ¶ Jour. de Phys. lii. 289.

hand.   Its fracture is smooth and conchoidal; it does not adhere to the tongue, and has not the common appearance of an earthy body.   In this state Saussure gives it the name of *gelatinous alumina.**

Davy was naturally led by his previous discoveries to consider alumina as a metallic oxide.   His experiments leave little doubt on the subject, though he did not succeed in obtaining the metal in a separate state.   When potassium is passed through alumina heated to whiteness, a considerable proportion of it is converted into potash, and gray metallic particles are perceived in the mass, which effervesce in water and are converted into alumina.   'When a globule of iron is fused by galvanism in contact with moist alumina, it forms an alloy with aluminum.   It effervesces slowly in water, being covered with a white powder.†   To this metallic basis Davy gave the name of *aluminum.*

But it is to Wöhler that we are indebted for a method of obtaining *aluminum* in a state of purity, and for determining its properties.‡

Professor Œrsted first discovered that when dry alumina is intimately mixed with charcoal powder, and a current of dry chlorine gas is passed through the mixture while heated to redness in a porcelain tube, an anhydrous chloride of aluminum is formed.§   To form this chloride the best process is to mix intimately hydrate of alumina well washed and dried with a quantity of charcoal powder, sugar, and oil, to make the whole up into a ball, and to heat it in a covered crucible till the sugar and oil are decomposed.   The black matter thus obtained is put into a porcelain tube, and a current of dry chlorine gas passed over it while heated to redness.   The chloride of aluminum sublimes and gradually obstructs the farther extremity of the porcelain tube.   It is a solid crystalline body having a pale greenish yellow colour, semitransparent, and in plates. In the air it smokes feebly and soon deliquesces.   When thrown into water it dissolves with the evolution of great heat.   It is volatilized at a temperature not much higher than that of boiling water, and it fuses at a heat not very different from that at which it is volatilized.   It was by decomposing this chloride that Wöhler obtained pure aluminum.   His method was as follows :

* Jour. de Phys. lii. 290.   † Elements of Chemical Philosophy, p. 355.
‡ Poggendorf's Annalen. xi. 146.
§ Schweigger's Jahrbuch, xv. 368.

Some pieces of potassium, well freed from naphtha, are put into the bottom of a porcelain or platinum crucible, over which nearly an equal volume of chloride of aluminum is put. The lid of the crucible should be tied down with an iron wire. The crucible is now heated by a spirit lamp, at first gently, and then more briskly. The greatest quantity of potassium employed was a piece about the size of a pea. At the instant of decomposition a very violent heat is evolved, which raises the crucible instantly to redness. The matter in the crucible is fused and of a grayish-black colour. When quite cold it is plunged into a large vessel filled with water to remove the potash, and weaken its action so as to prevent it from acting on the aluminum. During the solution a little fetid hydrogen gas is exhaled, and there remains undissolved a gray powder, which viewed by a microscope in the sun, appears to consist of small metallic plates. The water is drawn off, and new water being added, the aluminum is collected on a filter, washed, and dried.

Aluminum in this state has a great resemblance to platinum. When burnished it assumes the metallic lustre and the splendour of tin. When rubbed in a mortar the scales admit of compression, and then constitute larger scales, so that in all probability it is a malleable metal. It is not fusible at the temperature at which cast-iron melts. When exposed to a strong heat surrounded with charcoal powder it undergoes no alteration. In powder it is a non-conductor of electricity; but iron is also a non-conductor when in powder, as when reduced from oxalate of iron by heat. When heated to redness it takes fire, burns with extreme splendour, and is converted into alumina, which by the violence of the heat, if the combustion be in oxygen, is fused into a button hard enough to cut glass, almost as hard as sapphire.

It is not oxidized in water at the common temperature of the air, and water may be evaporated off aluminum without altering it; but when that liquid is raised to the boiling temperature the aluminum begins to decompose it, and hydrogen gas is given out slowly. But this process is very slow and imperfect. At the ordinary temperature aluminum is not attacked by concentrated sulphuric acid nor by nitric acid. But when heated it dissolves rapidly in the former of these acids, sulphurous acid being evolved. It dissolves in dilute sulphuric acid, and in muriatic acid with the evolution of hydrogen gas. It dissolves with the evolution of hydrogen gas

in very dilute solutions of potash, and even of ammonia, and the quantity of alumina which that alkali can dissolve in this way is very great. When heated in chlorine gas it takes fire and is converted into chloride of aluminum.[*]

Oxide.   II. So far as is known at present, aluminum unites with only one proportion of oxygen, and forms the base usually distifiguished by the name of *alumina.*

Alumina.   Alumina is a fine white-coloured powder destitute of taste and smell, but adhering strongly to the tongue. It is insoluble in water and alcohol ; but dissolves readily in caustic alkalies, and in a small degree it is soluble in ammonia, and even carbonate of ammonia. It dissolves slowly in sulphuric acid when assisted by heat, forming a colourless solution. When sulphate of potash is mixed with this solution, octahedral crystals of alum gradually form in it. It dissolves also in muriatic acid when digested in it for some time, even after having been ignited.

Alumina, when exposed to a very violent heat, produced by directing a stream of oxygen gas upon burning charcoal, undergoes a commencement of fusion, and is converted into a white enamel, semitransparent, and excessively hard.[†] If we put any confidence in the calculation of Saussure, the temperature necessary for producing this effect is as high as 1575° Wedgewood.[‡] The specific gravity of anhydrous alumina is 4·200.[§]

Atomic weight.   I have shown by experiments, which I consider as decisive, that the atomic weight of alumina is 2·25.[||] It is obvious from many circumstances that it is a compound of

1 atom aluminum	.	.	1·25
1 atom oxygen	.	.	1
			———
			2·25

So that the atomic weight of aluminum is 1·25.

Hydrates.   Though alumina be insoluble in water, yet its affinity for that liquid is very considerable. When dry alumina is exposed to a moist atmosphere, it speedily increases in weight (by absorbing water) 15 per cent. There is a white stalactitical looking mineral called Gibsite, found in North America, which is a hydrate of alumina composed of

* Wöhler, Poggendorf's Annalen. xi. 155.
† Morveau, Jour. de l'Ecole Polytechnique, I. iii. 299.
‡ Jour. de Phys. 1794.   § Annals of Philosophy (2d series), iii. 392.
|| Ibid. 161; First Principles, i. 287.

1 atom alumina	. .	2·25
1 atom water	. .	1·125

3·375

When alumina precipitated from its solution in potash by neutralization and ammonia and well washed, is allowed to dry in the open air in a temperature of about 60°, it is converted into a dry mass composed very nearly of

1 atom alumina	. .	2·25
2 atoms water	. .	2·25

4·5

When this bihydrate is dried in a temperature of 100° it is converted into a simple hydrate. Bihydrate of alumina occurs also native, and so does a mineral called *diaspore* which is a dihydrate of alumina, or a compound of

2 atoms alumina	. .	4·5
1 atom water	. .	1·125

5·625

Alumina is one of the weakest of all the bases. It even seems to perform the functions of an acid in certain combinations which occur in the mineral kingdom. Thus *spinell* is a compound of 1 atom magnesia and 6 atoms alumina. The magnesia is obviously the base and the alumina is the acid. The affinity between alumina and magnesia is great Hence in chemical analyses we sometimes get a compound of the two. It is easily distinguished from pure alumina by the property which it has of becoming hot when moistened with water.*

Possesses acid properties.

* Unverdorben has shown that it forms definite compounds with several of the bases. He dissolved it to saturation in caustic potash, and then separated the compound by means of alcohol in which it is insoluble. He showed that it was a compound of

Potash	. .	47·87 or 6
Alumina	. .	52·13 or 6·53

100·00

This is very nearly 3 atoms alumina and 1 atom potash. It is therefore a teraluminate of potash. When muriate of barytes is added to this solution, aluminate of barytes falls composed of

Barytes	. .	59·83 or 9·6
Alumina	. .	40·17 or 6·38

100·00

III. The anhydrous chloride of aluminum has been already described in the former part of this section. Nothing has been ascertained respecting the bromide and iodide of aluminum.

IV. The combinations which aluminum may be capable of forming with hydrogen, azote, carbon, boron, and silicon, are unknown.

Phosphuret.

V. When aluminum is heated to redness, when surrounded by an atmosphere of phosphorus, it takes fire and burns with considerable brilliancy. The phosphuret is a powder of a grayish-black colour, and which, when burnished, acquires the metallic lustre and gives out the smell of phosphuretted hydrogen. When put into water phosphuretted hydrogen is given out, which does not take fire in contact with air.[*]

Sulphuret.

VI. Sulphur may be distilled with aluminum without any combination taking place. But if the vapour of sulphur be made to pass over aluminum at a strong red heat, the combination takes place with a very vivid combustion. Sulphuret of aluminum is black, semi-metallic, and acquiring lustre when burnished. When left in the air it emits a strong smell of sulphuretted hydrogen, and falls at last into a grayish-white powder. When put upon the tongue it gives a sharp and hot taste, with the flavour of sulphuretted hydrogen. When thrown into water it gives out sulphuretted hydrogen rapidly, and alumina precipitates. When sulphate of alumina is heated to redness, and a current of hydrogen gas passed over it, the acid flies off and leaves the alumina unaltered.[†]

Seleniet.

VII. When aluminum is mixed with selenium and heated to redness, a combination takes place with the evolution of heat. The seleniet is a black powder, which, when burnished, assumes somewhat of a metallic lustre. When thrown into water selenietted hydrogen is given out with rapidity, and the water assumes a red colour from the selenium disengaged.[‡]

Arseniet.

VIII. When arsenic and aluminum are mixed and heated

It is therefore very nearly a teraluminate of barytes. By muriate of lime the aluminate of lime may be obtained composed of

| Lime | . | . | 35·66 or 3·5 |
| Alumina | . | . | 64·34 or 6·31 |

100·00.

This also is nearly a teraluminate of lime. We see from this that alumina enters into definite compounds as an acid. See Poggendorf's Annalen, vii. 323.

[*] Wöhler; Poggendorf's Annalen, xi. 160.   [†] Ibid. 159.   [‡] Ibid. 160.

to redness they unite with a feeble evolution of heat. The
arseniet is a black powder, which assumes the metallic lustre when burnished, and emits the smell of arsenietted hydrogen. When thrown into water it appears at first to undergo no change; but at last begins to give out arsenietted hydrogen. And when heat is applied the evolution of this gas becomes rapid.*

IX. When a mixture of tellurium in powder and aluminum Telluret. was heated to redness, a violent incandescence took place, and the whole matter was driven out of the tube with an explosion. This explosion is avoided by employing tellurium in masses. Telluret of alluminum is a black, brittle mass, having the metallic lustre. When exposed to the air it gives out an unsupportable odour of telluretted hydrogen; and when thrown into water, gas is given out with rapidity. The water becomes red, then brown, and at last opaque, in consequence of the tellurium which separates. This telluret is decomposed more rapidly in water than sulphuret of aluminum itself.†

X. Wöhler did not succeed in combining antimony and aluminum by heating the two metals together. The other alloys of aluminum are still unknown.

SECTION II.—OF GLUCINUM.

The *beryl* is a transparent stone, of a green colour, and a History. considerable degree of hardness, which is found crystallized in the mountains of Siberia, and in many other parts. Vauquelin analyzed this mineral in 1798, at the request of Haüy, to determine whether it was formed of the same ingredients with the emerald, as Haüy had conjectured from mineralogical considerations. The result of the analysis was a confirmation of the suspicions of Haüy, and the discovery of a new earth, to which Vauquelin and his associates gave the name of *glucina.*‡ The experiments of Vauquelin were repeated by Klaproth§ and other eminent chemists.

To obtain glucina pure, the beryl or the emerald, reduced to powder, is to be fused with thrice its weight of potash. The mass is to be diluted with water, dissolved in muriatic acid, and the solution evaporated to dryness. The residuum is to be mixed with a great quantity of water, and the whole thrown on a filter. The silica, which constitutes more than half the weight of the stone, remains behind; but the glucina

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* Wöhler; Poggendorf's Annalen, p. 160.   † Ibid. p. 161.
‡ Ann. de Chim. xxvi. 155.   § Beitrage, iii. 215.

Chap. III.

1 Part of water at	Takes up of lime	Takes up of dry hydrate
60°	$\frac{1}{78}$	$\frac{1}{384}$
130	$\frac{1}{972}$	$\frac{1}{729}$
212	$\frac{1}{1270}$	$\frac{1}{932}$

Lime water, as this solution is called, is limpid, has an acrid taste, and changes vegetable blue colours to green. It is usually formed by throwing a quantity of lime in powder into pure water, allowing it to remain for some time in a close vessel, and then decanting the transparent solution from the undissolved lime. When lime-water is exposed to the air, a stony crust soon forms on its surface composed of carbonate of lime; when this crust is broken it falls to the bottom, and another succeeds it; and in this manner the whole of the lime is soon precipitated, by absorbing carbonic acid from the air.

The smell perceived during the slacking of lime is owing to a part of that earth being elevated along with the vapour of the water; as evidently appears from this circumstance, that vegetable blues exposed to this vapour are converted into green.

Burning of lime explained.

Limestone and chalk, though they are capable of being converted into lime by *burning*, possess hardly any of the properties of that active substance. They are tasteless, scarcely soluble in water and do not perceptibly act on animal bodies. Now, to what are the new properties of lime owing? What alteration does it undergo in the fire?

It had been long known, that limestone loses a good deal of weight by being burned or *calcined*. It was natural to suppose, therefore, that something is separated from it during calcination. Accordingly, Van Helmont, Ludovicus, and Macquer, made experiments in succession, in order to discover what that *something* is; and they concluded from them that it is *pure water*, which the lime recovers again when exposed to the atmosphere. As the new properties of lime could hardly be ascribed to this loss, but to some other cause, Stahl's opinion, like all the other chemical theories of that wonderful man, was generally acceded to. He supposed that the new properties which lime acquired by calcination are owing entirely to the more minute division of its particles by the action of the fire. Boyle indeed had endeavoured to prove that these properties are owing to the *fixation of fire* in the lime; a theory which was embraced by Newton and illustrated by Hales, and which Meyer new modelled, and explained with so much ingenuity and acuteness as to draw the attention of the most distinguished chemists. But while Meyer was thus employed

in Germany, Dr. Black of Edinburgh published, in 1756, those celebrated experiments which form so brilliant an era in the history of chemistry.

He first ascertained, that the quantity of water separated from limestone during its calcination is not nearly equal to the weight which it loses. He concluded in consequence, that it must have lost something else than mere water. What this could be, he was at first at a loss to conceive; but recollecting that Dr. Hales had proved that limestone, during its solution in acids, emits a great quantity of *air*, he conjectured that *this* might probably be what is lost during calcination. He calcined it accordingly, and applied a pneumatic apparatus to receive the product. He found his conjecture verified; and that the *air* and the *water* which separated from the lime were together precisely equal to the loss of weight which it had sustained. Lime therefore owes its new properties to the loss of *air;* and limestone differs from lime merely in being combined with a certain quantity of *air !* for he found that, by restoring again the same quantity of *air* to lime, it was converted into limestone. This air, because it existed in lime in a fixed state, he called *fixed air.* It was afterwards examined by Dr. Priestley and other philosophers; found to possess peculiar properties, and to be that species of gas now known by the name of *carbonic acid gas.* Lime then is the simple substance, and limestone is composed of ·carbonic acid and lime. Heat separates the carbonic acid and leaves the lime in a state of purity.

When lime is exposed to the open air, it gradually attracts moisture, and falls to powder; after which it soon becomes saturated with carbonic acid, and is again converted into carbonate of lime or unburnt limestone.

My experiments, I conceive, leave no doubt that the atomic weight of lime is 3·5.* From the decomposition of lime by chlorine, it is pretty evident that it is a compound of one atom of base and 1 atom of oxygen. Hence its constituents must be

Calcium	. .	2·5
Oxygen	. .	1·0
		—
		3·5

and the atomic weight of calcium must be 2·5.

Lime is applied to a great variety of 'uses. It serves as a manure to land; it is employed as an antacid in medicine; it

* Annals of Philosophy (2d Series), i. 6.

is an excellent building stone, and it constitutes the essential ingredient in mortar.

Mortar is composed of quicklime and sand reduced to a paste with water. When dry it becomes as hard as stone, and as durable; and adhering very strongly to the surfaces of the stones which it. is employed to cement, the whole wall becomes in fact nothing else than one single stone. But this effect is produced very imperfectly unless the mortar be very well prepared.

The lime ought to be pure, completely free from carbonic acid, and in the state of a very fine powder: the sand should be free from clay, and partly in the state of fine sand, partly in that of gravel: the water should be pure; and if previously saturated with lime, so much the better. The best proportions, according to the experiments of Dr. Higgins, are 3 parts of fine sand, 4 parts of coarser sand, 1 part of quicklime recently slacked, and as little water as possible.

The stony consistence which mortar acquires is owing, partly to the absorption of carbonic acid, but principally to the combination of part of the water with the lime. This last circumstance is the reason, that if to common mortar one-fourth part of lime, reduced to powder without being slacked, be added, the mortar when dry acquires much greater solidity than it otherwise would do. This was first proposed by Loriot;* and a number of experiments were afterwards made by Morveau.† The proportions which this philosopher found to answer best are the following:

Fine sand	0·3
Cement of well baked bricks	0·3
Slacked lime	0·2
Unslacked lime	0·2
	1·0

The same advantages may be attained by using as little water as possible in slacking the lime. This was first pointed out by La Faye.‡

Higgins found that the addition of burnt bones improved mortar by giving it tenacity, and rendering it less apt to crack in drying; but they ought never to exceed one-fourth of the lime employed.

When a little clay is added to mortar, it acquires the important property of hardening under water; so that it may be

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* Jour. de Phys. iii. 231.   † Ibid. vi. 311.   ‡ Ibid. ix. 437.

employed in constructing those edifices which are constantly exposed to the action of water. Limestone is found not un-frequently mixed with clay: and in that case it becomes brown by calcination, instead of white. These native limestones are employed for making *water mortar;* but good water mortar may be made by the following process, first proposed by Morveau: Mix together 4 parts of blue clay, 6 parts of black oxide of manganese, and 90 parts of limestone, all in powder. Calcine this mixture to expel the carbonic acid, mix it with 60 parts of sand, and form it into mortar with a sufficient quantity of water.*

The best mortar for resisting water is made by mixing with lime puzzolano, a volcanic sand brought from Italy. Morveau informs us that *basaltes,* which is very common in this country, may be substituted for puzzolano. It must be heated in a furnace, thrown while red-hot into water, and then passed through a sieve to reduce it to the proper size.†

I find by analyzing Arden lime, near Glasgow, which con- Water mortar. stitutes an excellent water mortar, that it contains a considerable quantity of silica, and that when the lime is burnt the silica enters into chemical combination with it. For when the lime is dissolved in muriatic acid and the solution sufficiently concentrated, the silica gelatinizes. It seems to be this silicate of lime which gives the mortar the property of setting under water.

2. Peroxide of lime was discovered by M. Thenard. He Peroxide. obtained it by letting fall, drop by drop, limewater into deut-oxide of hydrogen. Small brilliant scales fall, which constitute the peroxide of lime. It undergoes spontaneous decomposition when kept under water, and cannot be dried in vacuo without losing its excess of oxygen. It is composed, according to Thenard, of

1 atom calcium	. ..	2·5
2 atoms oxygen	· . ..	2
		4·5

and its atomic weight is 4·5.

III. Chloride of calcium is easily formed by passing a cur- Chloride. rent of dry chlorine gas, over lime previously heated to redness. The oxygen of the lime is disengaged and chloride of calcium formed, as was first shown by Sir H. Davy. It may

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* Ann. de Chim. xxxvii. 259.   † Ibid. xxxvii. 262.

be obtained also by simply dissolving lime in muriatic acid, and crystalizing the solution. It possesses the characters of a salt, and will therefore be described in the second volume of this work.

The bromide and iodide of calcium are also salts, and will be described hereafter.

Chloride of lime. But chlorine has the property of combining with hydrate of lime, and of forming a compound which may be called *chloride of lime*. It was first made by Messrs. Tennant and Macintosh, of Glasgow, and has now become a most important article of commerce, under the name of bleaching powder. It is made by exposing slacked lime, in fine powder, in a chamber filled with chlorine gas, till it refuse to absorb any more. Some years ago, when examined by Mr. Dalton, it was a compound of 1 atom chlorine and 2 atoms lime; but of late years the quality has been so much improved that it is now (as manufactured in Glasgow,) a compound of

1 atom chlorine	.	4·5
1 atom lime	.	3·5
		——
		8

at least very nearly, for it dissolves in water leaving only a very slight residue, consisting chiefly of impurities in the lime, with a very little lime. This chloride has an exceedingly hot taste, and dissolves readily in water. Its bleaching properties are so considerable that it is always used in this country for the bleaching of cotton cloth, which is never now exposed to the sun upon grass as formerly. When exposed to the air it remains for some hours unaltered; but at last begins to absorb moisture, and flows ultimately into a liquid which consists of a solution of chloride of calcium. It has a peculiar smell, not quite the same, but analogous to that of chlorine. When heated it gives out oxygen gas mixed at first with a little chlorine.

How tested. The usual mode of determining the strength of bleaching powder, is to ascertain how much solution of indigo in sulphuric acid is discoloured by a given weight of the powder previously dissolved in water. But this method, notwithstanding the ameliorations introduced into it by Gay-Lussac, is, I think liable to considerable uncertainty. I have been in the habit myself of testing the bleaching powder by means of muriate of manganese, which it has the property of throwing down in the state of teroxide of manganese, and the weight of teroxide obtained measures the strength of the bleaching powder. The

only precaution necessary, is to take care that the solution of
the bleaching powder contains no free lime, which is almost
always the case. This excess must be exactly neutralized by
muriatic acid, and care must be taken not to add too much,
otherwise the result will not be exact. This makes the pro-
cess rather unfit for common bleachers; though it has been
recommended by Morin as preferable to the indigo test.* Mr.
Dalton proposed the addition of a solution of bleaching powder
to a solution of protosulphate of iron, till the smell of chlorine
begins to be perceived. And my friend Mr. Crum, one of the
most extensive bleachers in the neighbourhood of Glasgow, and
an excellent practical chemist, informs me that he always em-
ploys this method, and finds it both exact and delicate.

With respect to the nature of bleaching powder, two opinions
at present divide the chemical world. The first and the most
common one is, that it is a compound of chlorine and lime. The
second is that advanced by Berzelius; which must at present
be viewed in the light of an ingenious and plausible conjecture.
According to him chlorine and oxygen are capable of forming
an acid containing less oxygen than chloric acid, and which,
therefore, he calls *chlorous acid.* We do not yet know the
exact composition of this acid, but we may suppose it (for the
sake of explaining the nature of the chloride), a compound of
1 atom chlorine and 3 atoms oxygen. When the chlorine
comes in contact with the lime, three-fourths of the lime give
out their oxygen to 1 atom of chlorine, and convert it into
chlorous acid. This atom of chlorous acid unites to the remain-
ing fourth of the lime, and forms with it chlorite of lime, while
the three atoms of calcium evolved unite to chlorine, and form
chloride of calcium. According to this view of the subject
bleaching powder is a mixture of

<div style="text-align:center">

3 atoms chloride of calcium = 21
1 atom chlorite of lime = 11

</div>

So that nearly two-thirds of it is chloride of calcium, and little
more than one-third chlorite of lime. It is to the chlorite of
lime that the bleaching powers of the liquid are owing. Its
oxygen being loosely combined is given out, and acting on the
colouring matter of the cloth produces its bleaching effects.†

This opinion of Berzelius is founded chiefly upon the pro-
perties of the combination of chlorine and potash. It yields,

* Ann. de Chim. et de Phys. xxxvii. 142.
† Poggendorf's Annalen. xii. 529.

when evaporated, a peculiar salt which dissolves in water, and possesses bleaching properties. Faraday obtained a similar salt when the disinfecting liquid of Labaraque, formed by combining a determinate quantity of chlorine gas with solution of carbonate of soda is evaporated to dryness. No chlorine is given off during the evaporation, and the salt possesses peculiar properties, and has bleaching powers. These facts undoubtedly deserve the attention of chemists, and are sufficient to satisfy us that the nature of this combination has not yet been accurately determined. It is rather inconsistent, however, with the opinion of Berzelius, that bleaching powder does not attract moisture from the atmosphere nearly so fast as we would expect, from a substance containing so great a proportion of chloride of calcium, as his hypothesis would indicate. It is also remarkable that chlorine gas is evolved when sulphuric acid is dropt into a solution of bleaching powder. This does not happen when we pour that acid into a solution of chlorate of potash. I say nothing respecting the quateroxide of chlorine of Davy and Count Von Stadion, because the analysis of that oxide is probably inaccurate. Yet it would require to be proved so, before the existence of a chlorous acid couldbe admitted. The investigation of the nature of this substance is environed with many difficulties; but it is highly worthy the attention of chemists.

Phosphuret.   IV. Phosphuret of calcium may be formed precisely in the same way as phosphuret of barium. This phosphuret was first formed by Mr. Smithson Tennant. Phosphuret of calcium has a deep brown colour, and is moulded into the shape of the tube. It falls to pieces in the air. It is insoluble in water; but it has the property of decomposing that liquid. Phosphuretted hydrogen mixed with hydrogen gas is emitted, which takes fire as soon as it comes to the surface of the water.

This phosphuret has not yet been analyzed; but it is exceedingly probable that like phosphuret of barium it is a compound of

1 atom phosphate of lime	.	.	.	8
2½ atoms biphosphuret of calcium	.	.	11·25

V. Sulphur and calcium unite in various proportions. Three only of these sulphurets have been hitherto examined.

Sulphuret.   1. Sulphuret of calcium is obtained when we mix anhydrous sulphate of lime in· powder with about ⅕th of its weight of charcoal powder, and expose the mixture in a covered crucible to a white heat for a couple of hours. Its colour is reddish.

It dissolves imperfectly in water, but with great ease in muriatic acid, while a great quantity of sulphuretted hydrogen gas is evolved. On this account Berthier recommends this process as the easiest and cheapest for procuring sulphuretted hydrogen gas.* It may be obtained (but mixed with sulphate of lime), also when we heat a mixture of lime and sulphur cautiously to redness in a covered crucible. When thus prepared it is a pyrophorus, and is known under the name of phosphorus of Canton. This sulphuret is a compound of

1 atom sulphur	. .	2
1 atom calcium	. .	2·5
		——
		4·5

45 grains of it, when dissolved in muriatic acid, give out $21\frac{1}{4}$ grains of sulphuretted hydrogen gas.

2. *Bisulphuret of calcium* was discovered by Mr. Herschell. It may be obtained by boiling a mixture of slacked lime, sulphur, and water, and allowing the liquid to cool slowly before it be perfectly saturated with sulphur. Yellow coloured crystals separate, which are more abundant when allowed to form over the excess of lime and sulphur contained in the liquid. These crystals require 400 times their weight of water at 60° to dissolve them. But they are more soluble in boiling water. Their water of crystallization amounts to 43·45 per cent. of their weight. They consist of

2 atoms sulphur	. .	4
1 atom calcium	. .	2·5
		——
		6·5

It is obvious that the crystals consist of

1 atom bisulphuret of calcium	. .	6·5
$4\frac{1}{2}$ atoms water	. . . .	5·0625
		————
		11·5625

3. When sulphuret of calcium is boiled in water with sulphur, till no more sulphur can be dissolved, we form a persulphuret of calcium composed of

5 atoms sulphur	. .	10
1 atom calcium	.	2·5
		——
		12·5

* Ann. de Chim. et de Phys. xxiv. 275.

This persulphuret was proposed many years ago in Ireland as a substitute for potash ley in bleaching. Whether it be employed in any part of Ireland for this purpose I do not know. But the bleachers in this part of the country never make any use of it.

VI. Nothing is known respecting the combination of selenium and calcium, and scarcely any experiments have been made on the alloys which calcium may be capable of forming with the different metals.

<p style="text-align:center">SECTION VII.—OF MAGNESIUM.</p>

History.   About the beginning of the eighteenth century, a Roman canon exposed a white powder to sale at Rome as a cure for all diseases. This powder he called *magnesia alba*. He kept the manner of preparing it a profound secret; but in 1707 Valentini informed the public that it might be obtained by calcining the lixivium which remains after the preparation of nitre;* and two years after, Slevogt discovered that it might be precipitated by potash from the mother ley† of nitre.‡ This powder was generally supposed to be *lime*, till Frederic Hoffman observed that it formed very different combinations with other bodies.§ But little was known concerning its nature, and it was even confounded with lime by most chemists, till Dr. Black made his celebrated experiments on it in 1755. Margraff published a dissertation on it in 1759,‖ and Bergman another in 1775, in which he collected the observations of these two philosophers, and which he enriched also with many additions of his own.¶ Butini, of Geneva, likewise published a valuable dissertation on it in 1779.

Magnesia is never found native in a state of purity, but it may be prepared in the following manner : *Sulphate of magnesia*, a salt composed of this earth and sulphuric acid, exists in sea-water, and in many springs, particularly in some about Epsom; from which circumstance it was formerly called *Epsom salt.* This salt is to be dissolved in boiling water, and a boiling

* De Magnesia Alba.

† The mother ley is the liquid that remains after as much as possible of any salt has been obtained from it. Common salt, for instance, is obtained by evaporating sea-water. After as much salt has been extracted from a quantity of sea-water as will crystallize, there is still a portion of liquid remaining. This portion is the mother ley.

‡ Diss. de Magnesia Alba.

§ Obs. Phys. Chim. 1722, pp. 105 and 177.   ‖ Opus. ii. 20.

¶ Opus. i. 365.

solution of carbonate of soda added. The magnesia is precipitated in the state of a carbonate. It is then to be washed with a sufficient quantity of water, dried, and heated to redness.

Magnesia, thus obtained, is a very soft white powder, which has very little taste, and is totally destitute of smell. Its specific gravity is about 2·3.* It converts vegetable blues to green.

Davy, after his decomposition of potash and soda, was naturally led to consider magnesia also to be a metallic oxide. He succeeded in decomposing it by the same process by which he decomposed the other alkaline earths. When moistened magnesia is exposed to the action of galvanism in contact with mercury, the earth is reduced, and its base amalgamated with mercury much more slowly than the other alkaline earths; owing probably to its insolubility in water. The process succeeds much more rapidly when moistened sulphate of magnesia is substituted for the pure earth. To the base of magnesia thus obtained, Davy gave the name of *magnesium.*

Magnesium is a white solid metal, having the appearance of silver; sinks rapidly in water, and of course is considerably heavier than that liquid. When the amalgam of magnesium is distilled in a glass tube filled with the vapour of naphtha, the metal appears to act upon the glass before the whole of the mercury is separated from it. Of course it is difficult to obtain it in a state of purity. When exposed to the air it rapidly absorbs oxygen, and is converted into magnesia. It decomposes water, separating the hydrogen, and combining with the oxygen; but not nearly so rapidly as the other metals obtained from the alkaline earths; owing, doubtless, to the insolubility of the magnesia in water. But when the water is acidulated with sulphuric acid, the decomposition of water and the formation of magnesia goes on with great rapidity.

M. Bussey has lately announced that by passing the vapour of potassium over the chloride of magnesium, heated to redness in a porcelain tube, the magnesium is disengaged and may be collected on a filter. It is in the state of brown flocks, which when rubbed in an agate mortar assume the metallic lustre, and resemble lead in appearance. According to Bussey, magnesium is not attacked by dilute nitric acid, but it is dissolved by muriatic acid. When heated before the blow-pipe it takes

Magnesium.

Properties.

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* Kirwan's Miner. i. 8.
† Davy's Electro-chemical Researches on the Decomposition of the Earths, &c. Phil. Trans. 1808.

fire, and is converted into magnesia.* I am not aware that this experiment of Bussey has been verified by any other chemist.

II. We are at present acquainted with only one oxide of magnesium; namely, *magnesia.*

Magnesia. Magnesia occurs in considerable quantity in the state of anhydrous carbonate. A whole range of low hills consisting of it is said to exist in India. In serpentine rocks it occurs in the state of a hydrate, composed of 1 atom magnesia and 1 atom water. Fine specimens of this hydrate occur at Swinaness in Unst, one of the Shetland islands, where it was discovered by Dr. Hibbert, traversing the serpentine, in veins. It occurs also at Hoboken in New Jersey. It occurs also in the state of a hydro-carbonate, a silicate, bisilicate, and tersilicate, and enters also as a constituent into a considerable number of minerals, in which it exists in the state of double or triple salt.

Magnesia is not melted by the strongest heat which it has been posssible to apply; but Mr. Darcet observed that, in a very high temperature, it became somewhat agglutinated. When formed into a cake with water, and then exposed to a violent heat, the water is gradually driven off, and the magnesia contracts in its dimensions; at the same time, as Mr. Tingry informs us, it acquires the property of shining in the dark when rubbed upon a hot iron plate. Dr. Clarke, by a stream of oxygen and hydrogen gases, fused it with great difficulty into a white enamel.

Butini of Geneva showed, many years ago, that carbonate of magnesia is soluble in water, and more soluble in cold than in hot water. The subject was taken up about ten years ago by Dr. Fife of Edinburgh, who ascertained that at 212°, 1 part of magnesia requires 36,000 parts of water to dissolve it, but at the temperature of 60°, 1 part of magnesia requires for solution only 5760 parts of water. Carbonate of magnesia is soluble in 2493 parts of cold, and requires 9000 parts of boiling hot water to dissolve it.†

How detected. 1. Caustic magnesia does not solidify water like barytes, strontian, and lime; hence it does not become hot when water is thrown on it. Neither does it absorb carbonic acid gas from the atmosphere. It has a strong affinity for silica. Dr. Wollaston first pointed out a method of detecting the presence of the minutest quantity of magnesia in minerals. His method

is as follows: Dissolve in a watch glass a minute fragment of the mineral.* Render the solution neutral by cautious eva-poration; then while hot add a little oxalate of ammonia to precipitate any lime which it may contain. Let the precipitate fall, and take a few drops of the clear liquid and put them on a slip of window-glass. Add a drop or two of bicarbonate of ammonia, and afterwards a drop or two of biphosphate of ammonia. Then draw a little of the clear solution to one side with a glass rod, and trace any letters or lines across it with a glass rod. On exposing it to a gentle heat, white traces will be perceived wherever the rod was applied.

It has been ascertained that sulphate of magnesia (abstract-ing the water) is a compound of _Atomic weight._

Sulphuric acid	. .	5
Magnesia	. .	2·5
		———
		7·5

Now the salt is neutral, and consequently the atomic weight of magnesia is 2·5. From Davy's experiments, it is clear that magnesia is a compound of

1 atom magnesium	. .	1·5
1 atom oxygen	. .	1

Consequently the atomic weight of magnesium is 1·5.

III. When magnesia is heated in chlorine gas it parts with _Chloride._ its oxygen, and is converted into chloride of magnesium. As this chloride possesses the characters of a salt, the account of it is deferred to the second volume of this work. For the same reason the bromide and iodide of magnesium will occupy our attention afterwards.

IV. Nothing is known respecting any compounds which magnesium may be capable of forming with hydrogen, azote, carbon, boron, silicon, or phosphorus.

V. No accurate experiments have hitherto been made upon _Sulphuret._ the formation of the sulphuret of magnesium. Berthier, who formed so many sulphurets by heating sulphates with charcoal, does not appear to have tried the sulphate of magnesia. If we mix hydrate of magnesia with water, and pass a current of sulphuretted hydrogen gas through the solution, as long as that

* If it is not soluble it must be rendered so by previous fusion with car-bonate of soda.

gas continues to be absorbed, filter the solution, and boil it in a retort, the uncombined sulphuretted hydrogen gas is driven off, and a white mucilaginous matter falls down, which is a sulphuret of magnesium. The same sulphuret is obtained when hydrosulphuret of potash is mixed with a solution of sulphate of magnesia.

When caustic magnesia and sulphur are boiled in water, a sulphuret of magnesium is gradually dissolved. But the process is tedious, and yields a very small quantity of product. We do not succeed in forming a sulphuret when we heat magnesia and sulphur together in a crucible. The sulphur flies off and leaves the magnesia unaltered.

VI. Nothing is known respecting the seleniet of magnesium or of the alloys which it may be capable of forming with the metals.

THE OXIDES of these seven metals constitute the most powerful alkaline bodies. They all combine readily with acids, and form *salts*. These salts have been more completely investigated than any others. An account of them will be given in a subsequent part of this work. All the chlorides, bromides, and iodides of these bodies are also salts. The order of the affinity of these bodies for acids is as follows:

Barytes,	Lime,
Strontian,	Lithia?
Potash,	Magnesia.
Soda,	

But to this order there are some exceptions. For example, lime unites to oxalic acid in preference to any of the other bases, when they are all in solution together.

FAMILY II.—EARTHY BASES.

The six bodies belonging to this family, when united to oxygen, form white, tasteless powders, insoluble in water, and formerly distinguished by the name of *earths*. It is now known that there is no true distinction between *earths* and *metallic oxides*. But the six bases included in this family have so many properties in common, that it is proper to consider them together. And for want of a better name I have distinguished the family by the term *Earthy*, which was formerly applied to the oxides of these bases.

SECTION I.—OF ALUMINUM.

Alum is a salt which was known many centuries ago, and employed in dyeing, though its component parts were unknown. The alchymists discovered that it is composed of sulphuric acid and an earth ; but the nature of this earth was long unknown. Stahl and Neuman supposed it to be lime; but in 1728 Geoffroy, junior, proved this to be a mistake, and demonstrated, that the earth of alum constitutes a part of clay.* In 1754, Margraff showed that the basis of alum is an earth of a peculiar nature, different from every other ; an earth which is an essential ingredient in clays, and gives them their peculiar properties.† Hence this earth was called *argil;* but Morveau afterwards gave it the name of *alumina,* because it is obtained in the state of greatest purity from alum. The properties of alumina were still farther examined by Macquer in 1758 and 1762,‡ by Bergman in 1767 and 1771,§ and by Scheele in 1776;‖ not to mention several other chemists who have contributed to the complete investigation of this substance. A very ingenious treatise on it was published by Saussure, junior, in 1801.¶

Alumina may be obtained by the following process: Dissolve alum in water, and add to the solution an excess of carbonate of soda, and digest the mixture for some time to deprive the precipitated alumina of all the sulphuric acid with which it was united. Wash the precipitate with a sufficient quantity of water, dissolve it in muriatic acid, and precipitate the alumina from this solution by carbonate of ammonia. Digest the precipitate for some time in carbonate of ammonia. Then wash it and dry it. Pure alumina is easily obtained from ammoniacal alum, simply by exposing it to a strong red heat.

Alumina thus obtained assumes two very different appearances according to the way in which the precipitation has been conducted. If the earthy salt be dissolved in as little water as possible, the alumina has the appearance of a white earth, light, friable, very spongy, and attaching itself strongly to the tongue. In this state Saussure distinguishes it by the name of *spongy alumina.*

But if the salt has been dissolved in a great quantity of water, the alumina is obtained in a brittle transparent yellow coloured mass, splitting in pieces like roll sulphur when held in the

* Mem. Par. 1728, p. 303.
† Mem. Berlin, 1754 and 1759, Margraff, ii. 1. ‡ Mem. Paris.
§ Bergman, i. 287, and v. 71.
‖ Scheele, i. 191, French Transl.   ¶ Jour. de Phys. lii. 289.

hand.   Its fracture is smooth and conchoidal; it does not adhere to the tongue, and has not the common appearance of an earthy body.   In this state Saussure gives it the name of *gelatinous alumina.**

Davy was naturally led by his previous discoveries to consider alumina as a metallic oxide.   His experiments leave little doubt on the subject, though he did not succeed in obtaining the metal in a separate state.   When potassium is passed through alumina heated to whiteness, a considerable proportion of it is converted into potash, and gray metallic particles are perceived in the mass, which effervesce in water and are converted into alumina.   When a globule of iron is fused by galvanism in contact with moist alumina, it forms an alloy with aluminum.   It effervesces slowly in water, being covered with a white powder.†   To this metallic basis Davy gave the name of *aluminum.*

But it is to Wöhler that we are indebted for a method of obtaining *aluminum* in a state of purity, and for determining its properties.‡

Professor Œrsted first discovered that when dry alumina is intimately mixed with charcoal powder, and a current of dry chlorine gas is passed through the mixture while heated to redness in a porcelain tube, an anhydrous chloride of aluminum is formed.§   To form this chloride the best process is to mix intimately hydrate of alumina well washed and dried with a quantity of charcoal powder, sugar, and oil, to make the whole up into a ball, and to heat it in a covered crucible till the sugar and oil are decomposed.   The black matter thus obtained is put into a porcelain tube, and a current of dry chlorine gas passed over it while heated to redness.   The chloride of aluminum sublimes and gradually obstructs the farther extremity of the porcelain tube.   It is a solid crystalline body having a pale greenish yellow colour, semitransparent, and in plates.   In the air it smokes feebly and soon deliquesces.   When thrown into water it dissolves with the evolution of great heat.   It is volatilized at a temperature not much higher than that of boiling water, and it fuses at a heat not very different from that at which it is volatilized.   It was by decomposing this chloride that Wöhler obtained pure aluminum.   His method was as follows :

* Jour. de Phys. lii. 290.   † Elements of Chemical Philosophy, p. 355.
‡ Poggendorf's Annalen. xi. 146.
§ Schweigger's Jahrbuch, xv. 368.

Some pieces of potassium, well freed from naphtha, are put
into the bottom of a porcelain or platinum crucible, over which
nearly an equal volume of chloride of aluminum is put.   The
lid of the crucible should be tied down with an iron wire.
The crucible is now heated by a spirit lamp, at first gently,
and then more briskly.   The greatest quantity of potassium
employed was a piece about the size of a pea.   At the instant
of decomposition a very violent heat is evolved, which raises
the crucible instantly to redness.   The matter in the crucible
is fused and of a grayish-black colour.   When quite cold it is
plunged into a large vessel filled with water to remove the
potash, and weaken its action so as to prevent it from acting
on the aluminum.   During the solution a little fetid hydrogen
gas is exhaled, and there remains undissolved a gray powder,
which viewed by a microscope in the sun, appears to consist of
small metallic plates.   The water is drawn off, and new water
being added, the aluminum is collected on a filter, washed, and
dried.

Aluminum in this state has a great resemblance to platinum. Properties.
When burnished it assumes the metallic lustre and the splendour
of tin.   When rubbed in a mortar the scales admit of compres-
sion, and then constitute larger scales, so that in all probability
it is a malleable metal.   It is not fusible at the temperature at
which cast-iron melts.   When exposed to a strong heat sur-
rounded with charcoal powder it undergoes no alteration.   In
powder it is a non-conductor of electricity; but iron is also a
non-conductor when in powder, as when reduced from oxalate
of iron by heat.   When heated to redness it takes fire, burns
with extreme splendour, and is converted into alumina, which
by the violence of the heat, if the combustion be in oxygen, is
fused into a button hard enough to cut glass, almost as hard as
sapphire.

It is not oxidized in water at the common temperature of
the air, and water may be evaporated off aluminum without
altering it; but when that liquid is raised to the boiling tem-
perature the aluminum begins to decompose it, and hydrogen
gas is given out slowly.   But this process is very slow and
imperfect.   At the ordinary temperature aluminum is not
attacked by concentrated sulphuric acid nor by nitric acid.
But when heated it dissolves rapidly in the former of these
acids, sulphurous acid being evolved.   It dissolves in dilute
sulphuric acid, and in muriatic acid with the evolution of
hydrogen gas.   It dissolves with the evolution of hydrogen gas

in very dilute solutions of potash, and even of ammonia, and the quantity of alumina which that alkali can dissolve in this way is very great. When heated in chlorine gas it takes fire and is converted into chloride of aluminum.[*]

Oxide.   II. So far as is known at present, aluminum unites with only one proportion of oxygen, and forms the base usually distinguished by the name of *alumina.*

Alumina.   Alumina is a fine white-coloured powder destitute of taste and smell, but adhering strongly to the tongue. It is insoluble in water and alcohol ; but dissolves readily in caustic alkalies, and in a small degree it is soluble in ammonia, and even carbonate of ammonia. It dissolves slowly in sulphuric acid when assisted by heat, forming a colourless solution. When sulphate of potash is mixed with this solution, octahedral crystals of alum gradually form in it. It dissolves also in muriatic acid when digested in it for some time, even after having been ignited.

     Alumina, when exposed to a very violent heat, produced by directing a stream of oxygen gas upon burning charcoal, undergoes a commencement of fusion, and is converted into a white enamel, semitransparent, and excessively hard.[†] If we put any confidence in the calculation of Saussure, the temperature necessary for producing this effect is as high as 1575° Wedgewood.[‡] The specific gravity of anhydrous alumina is 4·200.[§]

Atomic weight.   I have shown by experiments, which I consider as decisive, that the atomic weight of alumina is 2·25.[||] It is obvious from many circumstances that it is a compound of

1 atom aluminum	. .	1·25
1 atom oxygen	. .	1
		———
		2·25

So that the atomic weight of aluminum is 1·25.

Hydrates.   Though alumina be insoluble in water, yet its affinity for that liquid is very considerable. When dry alumina is exposed to a moist atmosphere, it speedily increases in weight (by absorbing water) 15 per cent. There is a white stalactitical looking mineral called Gibsite, found in North America, which is a hydrate of alumina composed of

* Wöhler, Poggendorf's Annalen. xi. 155.
† Morveau, Jour. de l'Ecole Polytechnique, I. iii. 299.
‡ Jour. de Phys. 1794.   § Annals of Philosophy (2d series), iii. 392.
|| Ibid. 161; First Principles, i. 287.

1 atom alumina   .   .   2·25
1 atom water   .'   .   1·125

                                        ―――
                                        3·375

When alumina precipitated from its solution in potash by neutralization and ammonia and well washed, is allowed to dry in the open air in a temperature of about 60°, it is converted into a dry mass composed very nearly of

1 atom alumina   .   .   2·25
2 atoms water   .   .   2·25

                                        ―――
                                        4·5

When this bihydrate is dried in a temperature of 100° it is converted into a simple hydrate. Bihydrate of alumina occurs also native, and so does a mineral called *diaspore* which is a dihydrate of alumina, or a compound of

2 atoms alumina   .   .   4·5
1 atom water   .   .   1·125

                                        ―――
                                        5·625

Alumina is one of the weakest of all the bases. It even seems to perform the functions of an acid in certain combinations which occur in the mineral kingdom. Thus *spinell* is a compound of 1 atom magnesia and 6 atoms alumina. The magnesia is obviously the base and the alumina is the acid. The affinity between alumina and magnesia is great Hence in chemical analyses we sometimes get a compound of the two. It is easily distinguished from pure alumina by the property which it has of becoming hot when moistened with water.*

* Unverdorben has shown that it forms definite compounds with several of the bases. He dissolved it to saturation in caustic potash, and then separated the compound by means of alcohol in which it is insoluble. He showed that it was a compound of

Potash   .   .   47·87 or 6
Alumina   .   .   52·13 or 6·53

                                ―――
                                100·00

This is very nearly 3 atoms alumina and 1 atom potash. It is therefore a teraluminate of potash. When muriate of barytes is added to this solution, aluminate of barytes falls composed of

Barytes   .   .   59·83 or 9·6
Alumina   .   .   40·17 or 6·38

                                ―――
                                100·00

III. The anhydrous chloride of aluminum has been already described in the former part of this section. Nothing has been ascertained respecting the bromide and iodide of aluminum.

IV. The combinations which aluminum may be capable of forming with hydrogen, azote, carbon, boron, and silicon, are unknown.

Phosphuret.

V. When aluminum is heated to redness, when surrounded by an atmosphere of phosphorus, it takes fire and burns with considerable brilliancy. The phosphuret is a powder of a grayish-black colour, and which, when burnished, acquires the metallic lustre and gives out the smell of phosphuretted hydrogen. When put into water phosphuretted hydrogen is given out, which does not take fire in contact with air.*

Sulphuret.

VI. Sulphur may be distilled with aluminum without any combination taking place. But if, the vapour of sulphur be made to pass over aluminum at a strong red heat, the combination takes place with a very vivid combustion. Sulphuret of aluminum is black, semi-metallic, and acquiring lustre when burnished. When left in the air it emits a strong smell of sulphuretted hydrogen, and falls at last into a grayish-white powder. When put upon the tongue it gives a sharp and hot taste, with the flavour of sulphuretted hydrogen. When thrown into water it gives out sulphuretted hydrogen rapidly, and alumina precipitates. When sulphate of alumina is heated to redness, and a current of hydrogen gas passed over it, the acid flies off and leaves the alumina unaltered.†

Seleniet.

VII. When aluminum is mixed with selenium and heated to redness, a combination takes place with the evolution of heat. The seleniet is a black powder, which, when burnished, assumes somewhat of a metallic lustre. When thrown into water selenietted hydrogen is given out with rapidity, and the water assumes a red colour from the selenium disengaged.‡

Arseniet.

VIII. When arsenic and aluminum are mixed and heated

It is therefore very nearly a teraluminate of barytes. By muriate of lime the aluminate of lime may be obtained composed of

Lime	. .	35·66 or 3·5
Alumina	. .	64·34 or 6·31
		100·00

This also is nearly a teraluminate of lime. We see from this that alumina enters into definite compounds as an acid. See Poggendorf's Annalen, vii. 323.

* Wöhler; Poggendorf's Annalen, xi. 160. † Ibid. 159. ‡ Ibid. 160.

to redness they unite with a feeble evolution of heat. The arseniet is a black powder, which assumes the metallic lustre when burnished, and emits the smell of arsenietted hydrogen. When thrown into water it appears at first to undergo no change; but at last begins to give out arsenietted hydrogen. And when heat is applied the evolution of this gas becomes rapid.*

IX. When a mixture of tellurium in powder and aluminum Telluret. was heated to redness, a violent incandescence took place, and the whole matter was driven out of the tube with an explosion. This explosion is avoided by employing tellurium in masses. Telluret of alluminum is a black, brittle mass, having the metallic lustre. When exposed to the air it gives out an unsupportable odour of telluretted hydrogen; and when thrown into water, gas is given out with rapidity. The water becomes red, then brown, and at last opaque, in consequence of the tellurium which separates. This telluret is decomposed more rapidly in water than sulphuret of aluminum itself.†

X. Wöhler did not succeed in combining antimony and aluminum by heating the two metals together. The other alloys of aluminum are still unknown.

SECTION II.—OF GLUCINUM.

The *beryl* is a transparent stone, of a green colour, and a History. considerable degree of hardness, which is found crystallized in the mountains of Siberia, and in many other parts. Vauquelin analyzed this mineral in 1798, at the request of Haüy, to determine whether it was formed of the same ingredients with the emerald, as Haüy had conjectured from mineralogical considerations. The result of the analysis was a confirmation of the suspicions of Haüy, and the discovery of a new earth, to which Vauquelin and his associates gave the name of *glucina*.‡ The experiments of Vauquelin were repeated by Klaproth§ and other eminent chemists.

To obtain glucina pure, the beryl or the emerald, reduced to powder, is to be fused with thrice its weight of potash. The mass is to be diluted with water, dissolved in muriatic acid, and the solution evaporated to dryness. The residuum is to be mixed with a great quantity of water, and the whole thrown on a filter. The silica, which constitutes more than half the weight of the stone, remains behind; but the glucina

* Wöhler; Poggendorf's Annalen, p. 160.   † Ibid. p. 161.
‡ Ann. de Chim. xxvi. 155.   § Beitrage, iii. 215.

and the other earths, being combined with muriatic acid, remain in solution. Precipitate them by means of carbonate of potash. Wash the precipitate, and then dissolve it in sulphuric acid. Add to the solution sulphate of potash; evaporate it to the proper consistency, and set it by to crystallize. Alum crystals gradually form. When as many of these as possible have been obtained, pour into the liquid carbonate of ammonia in excess, then filter and boil the liquid for some time. A white powder gradually appears, which is *glucina*. Besides the *beryl* or *emerald* there are two other minerals which contain glucina; namely, *euclase*, and *chrysoberyl*. It occurs also in *helvine*.

Glucina was reduced to the metallic state by Wöhler; by a process precisely similar to that employed for obtaining aluminum.* During the reduction so great a heat is evolved that the platinum crucible in which it is performed becomes white hot.

Properties. Glucinum thus obtained is a dark-gray powder; which when burnished acquires the metallic lustre. It must be very difficult of fusion. It does not absorb oxygen at the ordinary temperature of the air, and it may be kept under water even at a boiling heat without undergoing any alteration. When heated to redness in air or oxygen gas it burns with much splendour, and is converted into glucina, which, however, notwithstanding the violence of the heat, has not undergone fusion. It dissolves in concentrated sulphuric acid with the assistance of heat, while sulphurous acid is evolved. It dissolves readily in dilute sulphuric acid, and in muriatic acid with the evolution of hydrogen gas; and in nitric acid with the disengagement of deutoxide of azote. It dissolves also in potash ley, but not in ammonia.

Oxide. II. So far as is known at present it combines only with one proportion of oxygen and forms *glucina*.

Glucina. Glucina is a soft light white powder, without either taste or smell; which has the property of adhering strongly to the tongue. It has no action on vegetable colours. Its specific gravity is 2·976.† It is insoluble in water, but forms with a small quantity of that liquid a paste which has a certain degree of ductility. It does not combine with oxygen nor with any of the simple combustibles; but sulphuretted hydrogen dissolves it, and forms with it a hydrosulphuret, similar to other hydrosulphurets in its properties.‡

* Ann. de Chim. et de Phys. xxxix. 78.
† Ekeberg, Ann. de Chim. xliii. 277.   ‡ Fourcroy, ii. 159.

Glucina is soluble in the liquid fixed alkalies, in which it agrees with alumina. It is insoluble in ammonia, but soluble in carbonate of ammonia, in which respect it agrees with yttria; but it is about five times more soluble in carbonate of ammonia than that earth. It combines with all the acids, and forms with them sweet-tasted salts.*

I have shown by experiments which appear to me decisive, that the atomic weight of glucina is 3·25.† It is a compound of

1 atom glucinum	. .	2·25
1 atom oxygen	. .	1
		———
		3·25

consequently the atomic weight of glucinum is 2·25.

Hydrate of glucina is obtained when we precipitate the solution of glucina in muriatic acid by ammonia added in excess. It is a bulky white powder, similar to hydrate of alumina. No attempt has been made to determine the quantity of water which it contains.

III. Chloride of glucinum was first formed by M. Henry Rose, by passing a current of dry chlorine gas over a mixture of glucina and charcoal, heated to redness in a porcelain or glass tube. The chloride sublimes in the form of fine white needles. It is very volatile, and deliquesces speedily when exposed to the air. It was by heating a mixture of this chloride and potassium in a covered platinum crucible, that Wöhler obtained glucinum in the metallic state. Glucinum when heated in chlorine gas burns with much splendour, and is converted into chloride.

IV. When glucinum is heated in the vapour of bromine it takes fire, and is converted into bromide of glucinum. This bromide is in long white needles. It is very volatile, fusible, and dissolves in water with the evolution of much heat.‡

V. Glucinum burns equally when heated in the vapour of iodine. The iodide obtained sublimes in long white needles. It resembles the two preceding compounds.§

VI. Nothing is known respecting the compounds which glucinum may be capable of forming with hydrogen, azote, carbon, boron, and silicon.

VII. Glucinum burns when heated in the vapour of phos-

* Hence the name *glucina*, from γλυχος, *sweet*.
† First Principels, i. 318.
‡ Wöhler; Ann. de Chim. et de Phys. xxxix. 80.   § Wöhler; ibid.

phorus. The phosphuret formed is gray, and when put into water phosphuretted hydrogen gas is evolved.*

Sulphuret.

VIII. When glucinum is heated in the vapour of sulphur, it burns with almost as much splendour as in oxygen gas. The sulphuret is a gray mass which has not undergone fusion. It dissolves in water with difficulty, and without the evolution of sulphuretted hydrogen. When put into acid liquids that gas is given out very rapidly. Wöhler could not succeed in his attempts to convert sulphate of glucina into sulphuret of glucinum, by heating it in hydrogen gas or sulphuretted hydrogen gas. The sulphuric acid was driven off, and the glucina remained pure.†

Seleniet.

IX. Glucinum when heated with selenium, combines readily with the evolution of much heat. The seleniet fuses and constitutes a gray mass, having a crystalline texture. It dissolves with difficulty in water, and the liquid becomes red from the selenium disengaged.‡

Arseniet.

X. When glucinum is heated in contact with arsenic, light is evolved. The arseniet is a gray powder, which has not undergone fusion, and which, when put into water, disengages arsenietted hydrogen gas.§

Telluriet.

XI. Tellurium unites to glucinum without the disengagement of light. The telluret is a gray powder having the smell of telluretted hydrogen, and disengaging that gas with rapidity when put into water.‖

The remaining alloys of glucinum have not yet been examined.

SECTION LII.—OF YTTRIUM

History.

Some time before 1788, Captain Arhenius discovered, in the quarry of Ytterby in Sweden, a peculiar mineral different from all those described by mineralogists. Its colour is greenish-black, and its fracture like that of glass. It is magnetic, and generally too hard to be scratched by a knife. It is opaque, except in small pieces, when it transmits some yellow rays. Its specific gravity is 4·237.¶ A description of it was published by Geyer in 1788 in Crell's Annals, and by Rinman in his Miner's Lexicon. Professor Gadolin analyzed this mineral in 1794, and found it to contain a new earth; but though his

* Wöhler; Ann. de Chim. et de Phys. xxxix. 81.　† Ibid. p. 80.
‡ Ibid. p. 81.　§ Ibid.　‖ Ibid.
¶ Gadolin, Crell's Annals, 1796, i. 313.—Vauquelin, Ann. de Chim. xxxvi. 146.—Klaproth's Beitrage, iii. 58.

analysis was published in the Stockholm Transactions for 1794, and in Crell's Annals for 1796, it was some time before it drew the attention of chemical mineralogists. The conclusions of Gadolin were confirmed by Ekeberg in 1797, who gave to the new earth the name of *yttria*.* They were still farther confirmed and extended by Vauquelin in 1800,† and. likewise by Klaproth about the same time;‡ and Ekeberg published a new dissertation on the subject in the Swedish Transactions for 1802.§ Since that time it has been repeatedly examined by Berzelius, who has shown that the yttria, as examined by Gadolin and Ekeberg, was not pure. He has himself succeeded in separating it from most of the cerium with which it was contaminated, and has described its properties.||

Hitherto yttria has been found only in the black mineral first analyzed by Gadolin, and hence called *Gadolinite*, in which it is combined with black oxide of iron and the earth called silica; and in yttrotantalite, which from the description of Ekeberg is a compound of columbium and yttria, and a few kindred minerals. From the first, which is the most common, the yttria may be procured by treating the mineral reduced to powder with a mixture of nitric and muriatic acids, till it is completely decomposed; then filtering the solution, previously evaporated nearly to dryness, and diluting it with water. By this process the silica is left behind. The liquid which passes through the filter is to be evaporated to dryness, and the residue heated to redness for a considerable time in a close vessel, and then redissolved in water and filtered. What passes through the filter is colourless; when treated with ammonia a mixture of yttria and oxide of cerium falls. Heat this powder to redness, dissolve it in nitric acid, and evaporate to dryness to get rid of the excess of acid. Dilute with 150 parts of water, and put into the liquid a large excess of crystals of sulphate of potash. The crystals gradually dissolve, and after some hours a white precipitate will appear. This precipitate contains the oxide of cerium. Repeat the process to be sure of getting rid of the oxide of cerium. Filter the liquid, precipitate the yttria with pure ammonia; wash it well, and then heat it to redness.¶

* Crell's Annals, 1799, ii. 63.   † Ann. de Chim. xxxvi. 143.

‡ Ann. de Chim. xxxvii. 36, and Beitrage, iii. 52.

§ Kongl. Vetenskaps Acad. nya Handlingar, 1802, p. 68, and Jour. de Chim. iii. 78.

|| Annals of Philosophy, iii. 359. Afhandlingar i Fysik, Kemi och Mineralogi, iv. 217, 235.

¶ Berzelius, Afhandlingar, iv. 223.

Yttrium was first obtained in an isolated state from this earth by Wöhler.* The process followed was precisely the same as that by which aluminum and glucinum were obtained.

The yttrium was in the state of small scales, having the metallic lustre and the colour of iron. Its lustre is far inferior to that of aluminum. It is brittle, does not oxidize at the ordinary temperature in the air nor in water. When heated to redness it burns and is converted into yttria, and if the experiment be made in oxygen gas the splendour of the combustion can scarcely be surpassed. The yttria obtained is white, and exhibits evident marks of having been fused. Yttrium dissolves readily in dilute sulphuric acid, with the evolution of hydrogen gas. It dissolves with more difficulty in potash ley, and not at all in ammonia.†

II. So far as is known at present yttrium unites with only one proportion of oxygen, and forms yttria, which is a fine white

powder, and has neither taste nor smell. It has no action on vegetable blues. It is much heavier than any of the other earths; its specific gravity, according to Ekeberg, being no less than 4·842.

It is insoluble in water; yet it is capable of retaining a great proportion of that liquid, as is the case with alumina. Klaproth ascertained, that 100 parts of yttria, precipitated from muriatic acid by ammonia, and dried in a low temperature, lose 31 parts, or almost a third of their weight, when heated to redness in a crucible. Now this loss consists of pure water alone. It is not soluble in pure alkalies; but it dissolves readily in carbonate of ammonia, and in all the other alkaline carbonates. It combines with acids, and forms with them salts which have a sweet taste, and at the same time a certain degree of austerity.

The only person who has made experiments to determine the atomic weight of yttria, is Berzelius. He found the carbonate of yttria a compound of

Carbonic acid	.	.	2·75
Yttria	.	.	5·3825

And the sulphate of

Sulphuric acid	.	.	5
Yttria	.	.	5·4012‡

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* Ann. de Chim. et de Phys. xxxix. 81. † Wöhler; ibid.
‡ Annals of Philosophy, iii. 359. An analysis of crystallized sulphate of yttria, made in my laboratory by Mr. Steel, gave

The first of these analyses gives us 5·38, and the second 5·400 for the atomic weight of yttria. Wöhler has shown that the yttria when obtained by Berzelius's process is not quite free from potash, and that it contains also a trace of sulphuric acid.* It is clear, therefore, that the true atomic weight of yttria must be under these numbers. We cannot err very much, if we adopt 5·25 as the true atomic weight of this earth. It is obvious that yttria is a compound of

1 atom yttrium	.	.	4·25
1 atom oxygen	.	.	1
			————
			5·25

so that the atomic weight of yttrium is 4·25.

III. Chloride of yttrium is easily obtained by passing a current of dry chlorine gas over a mixture of yttria and charcoal, exposed to a red heat in a porcelain or glass tube. It was first formed by Wöhler. It has a strong resemblance to chloride of glucinum; being in white brilliant needles, which easily melt into a crystalline mass. It is volatile, dissolves in water with the evolution of much heat, and speedily deliquesces in the air.† *Chloride.*

IV. The bromide and iodide of yttrium have not yet been formed. Doubtless they will resemble those of glucinum.

V. Nothing is known respecting the compounds which yttrium may be capable of forming with hydrogen, azote, carbon, boron, or silicon.

VI. When heated in the vapour of phosphorus, it combines with a lively combustion. The phosphuret is a grayish-black powder, which gives out phosphuretted hydrogen gas when put into water.‡ *Phosphuret.*

VII. It takes fire also when heated in the vapour of sulphur. The sulphuret formed is a gray powder, which is insoluble in water, and does not undergo spontaneous decomposition. But when treated with an acid, it dissolves with the evolution of sulphuretted hydrogen gas.§ *Sulphuret.*

VIII. Selenium unites with yttrium when the two substances are heated together till the selenium fuses. A feeble *Seleniet.*

Sulphuric acid	.	.	5
Yttria	.	.	5·44
Water	.	.	3·19

This rather favours the notion that the atomic weight of yttria is 5·5. But the experiment will require repetition. It is excessively difficult to free yttria from all traces of cerium oxide, which doubtless increases the weight.

* Ann. de Chim. et de Phys. xxxix. 82.   † Wöhler; ibid. p. 81.
‡ Ibid. p. 84.   § Ibid. p. 83.

incandescence takes place. The seleniet is black and does not decompose water, but when put into dilute acids it gives out selenietted hydrogen gas.*

IX. Nothing is known respecting the alloys which yttrium may be capable of forming with the different metals.

<div align="center">SECTION IV.—OF CERIUM.†</div>

History. In the year 1750 there was discovered in the copper mine of Bastnâs at Ridderhytta, in Westmannland in Sweden, a mineral which, from its great weight, was for some time confounded with *tungsten*. This mineral is opaque, of a flesh colour, with various shades of intensity, and very rarely yellow. Its streak is grayish white, and when pounded it becomes reddish gray. It is compact, with a fine splintery fracture, and fragments of no determinate form; moderately hard; its specific gravity, according to Cronstedt, 4·988,‡ according to Klaproth 4·660,§ according to Messrs. Hisinger and Berzelius, from 4·489 to 4·619.|| This mineral was first examined by M. D'Elhuyar, the result of whose analysis was published by Bergman in 1784.¶ It ascertained that the mineral in question contained no tungsten.

No farther attention was paid to this mineral till Klaproth published an analysis of it in 1804, under the name of *Ochroits*,** and announced that it contained a *new earth*, to which he gave the name of *ochroita*. He sent a specimen of this new product to Vauquelin, who made a few experiments on it, but hesitated whether to consider ochroita as an earth or a *metallic oxide*.†† Meanwhile the mineral had undergone a still more complete examination in Sweden by Hisinger and Berzelius, who gave it the name of *cerit;* detected in it a peculiar substance, which they considered as a metallic oxide, and to which they gave the name of *cerium*, from the planet *Ceres*, lately discovered by Piazzi.‡‡ But the attempts of these chemists to reduce the supposed oxide to the metallic state were unsuccessful. Nor

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* Wöhler; Ann. de Chim. et de Phys. p. 84.

† I have placed cerium immediately after yttrium, because the properties of yttria and protoxide of cerium are identical. I never had an opportunity of making any experiments on yttria till the winter of 1829, when I was lucky enough to procure a few ounces of gadolinite from which I extracted it. The close resemblance between its properties and those of protoxide of cerium struck me with astonishment.

‡ Gehlen's Jour. i. 305.   § Ibid. || Ibid. ii. 398.

¶ Opusc. vi. 108.   ** Gehlen's Jour. ii. 203.

†† Ann. de Chim. l. 140.   ‡‡ Gehlen's Jour. ii. 297.

were the subsequent trials of Gahn, to reduce it by violent heat along with charcoal, or to alloy it with other metals, attended with greater success.* Vauquelin re-examined it; but his attempts were only partially successful.† They demonstrate, however, that the substance in question is a metal; though from its refractory nature, and its volatility, only minute globules of it were obtained.

In 1814 a new set of experiments on it were published by Laugier.‡ He appears to have reduced it to the metallic state, but, instead of the pure metal, obtained only a carburet. Hisinger had previously endeavoured to determine the composition of its oxides.§

To obtain the metal, the combination of oxide of cerium with tartaric acid was mixed with some lamp-black and oil, and exposed to the violent heat of a forge in a crucible lined with charcoal, and enclosed in another filled with sand. Only a small metallic button was obtained, not exceeding the fiftieth part of the oxide of cerium exposed to heat. It was white, brittle, dissolved with great difficulty in nitro-muriatic acid, and proved a mixture of iron and cerium. Another attempt to obtain the metal by heating its tartrate in a porcelain retort was not more successful. Most of it was dissipated, small globules only remaining, which proved as before, a mixture of cerium and iron.||

Laugier has shown that oxalic acid precipitates the whole of the oxide of cerium, and thus separates it from iron. He employed the oxide from the oxalate, and exposed it to a strong heat made up into a paste with oil. He affirms that it is not volatile. But an experiment made in Mr. Children's laboratory demonstates the contrary. Oxalate of cerium, which I had prepared, was exposed to the heat of a furnace, urged by bellows in a crucible of charcoal: it was completely volatilized.¶

Mosander has shown that cerium may be obtained in the metallic state, by the same process which succeeds with aluminum, glucinum, and yttrium. He heated the chloride of cerium mixed with potassium in a platinum crucible. The decomposition was attended with the evolution of much heat. The gray mass obtained being washed in water, metallic cerium

Cerium.

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* Gehlen's Jour. iii. 217.   † Ann. de Chim. iv. 28.
‡ Ibid. lxxxix. 317.
§ Memoirs of the Stockholm Academy for 1813, and Annals of Philosophy, iv. 355.
|| Ann. de Chim. liv. 59.   ¶ Annals of Philosophy, ii. 147.

remains under the form of a gray powder, having the metallic lustre.* The other properties of this metal have not yet been determined.

Oxides. I. Cerium combines with two proportions of oxygen, and forms two *oxides*. The protoxide is white and forms salts, having a light flesh colour. The peroxide has a reddish brown colour.

1. Peroxide. To procure peroxide of cerium in a state of purity, the Swedish chemists employed the following method : The mineral was reduced to a fine powder, and digested in nitric acid till every thing soluble was taken up. The solution being decanted off is evaporated to dryness, and the residue dissolved in water. Into this solution ammonia is poured, till every thing precipitable by means of it is thrown down. This precipitate being well washed is redissolved in nitric acid ; the acid is neutralized ; and then *tartrate of potash*† is added to the solution. The precipitate which is separated being heated to redness, and well washed with vinegar, and dried, is pure peroxide of cerium.‡ We may also precipitate the oxide of cerium from the nitric acid solution, by means of oxalate of ammonia.

Properties. The peroxide thus obtained has a reddish brown colour, is tasteless, and may be exposed to a strong heat without alteration ; but when strongly heated in a charcoal crucible it is volatilized. It dissolves in acids, though not very readily ; the solution has a reddish brown colour. When we digest it in muriatic acid, chlorine is disengaged, and the solution at first brown becomes gradually less and less coloured, till at last it is white, or at least has only a light shade of flesh red. By this 2. Protoxide. process it is gradually converted into protoxide. This protoxide may be precipitated in the state of a white powder by an alkali. But it is best to throw it down by carbonate of ammonia. It is then a white, light, tasteless powder in small scales. It is not altered by keeping, and dissolves readily in acids. The salts which it forms have a sweet taste like those of yttria. They bear a close resemblance to the similar salts of yttria, so that it is not easy to distinguish the one from the other. The salts of cerium are apt to acquire a brown colour from exposure to the air, which is not the case with the salts of yttria.

By a careful analysis of protosulphate of cerium, I found it composed of

* Gmelin's Handbuch der Theor. Chemie, i. 681.
† A salt to be described hereafter.   ‡ Gehlen's Jour. ii. 401.

Sulphuric acid	. .	5
Protoxide of cerium	. .	7·25*

Hisinger analyzed the protochloride of cerium, and extracted from a given weight of it

Chlorine	. .	6·926 or 4·5
Protoxide of cerium	. .	10·01 or 6·5†

By my experiments the atomic weight of protoxide of cerium is 7·25, while by those of Hisinger it is only 6·5. I think it possible that in my experiment the weight of the oxide may have been a little overrated in consequence of the whole sulphuric acid not having been disengaged. But certainly the error of Hisinger must be much farther on the other side. Till the point is settled by a new analysis of some salt of cerium upon a greater scale than it was in my power to make mine, in consequence of the very small quantity of oxide of cerium in my possession, I am disposed to adhere to my own determination as certainly not far from the truth.‡ If the protoxide be a compound of

<div style="text-align:right">Atomic weight.</div>

1 atom cerium	. .	6·25
1 atom oxygen	. .	1
		————
		7·25

then the atomic weight of cerium will be 6·25. Hisinger, from some rather imperfect analyses of the carbonates of cerium,§ has concluded that the oxygen in the two oxides of this metal are to each other as 2 to 3. If this supposition be admitted (and it ought to be subjected to a new examination,)

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* First Principles, i. 382. † Annals of Philosophy, iv. 355.

‡ Klaproth's analysis of protocarbonate of cerium comes much nearer my numbers than those of Hisinger. He found the constituents

Carbonic acid	. .	23 or 2·75
Protoxide	. .	65 or 7·77
Water	. .	12
		————
		100

§ He found the percarbonate of cerium composed of

Carbonic acid	. .	36·17
Peroxide of cerium	. .	63·83
		————
		100·00

Now if we consider this salt as a sesquicarbonate we shall obtain 7·28 for the atomic weight of peroxide. For 36·17 : 63·83 :: 4·125 (1½ atom carbonic acid) : 7·28. Now this considerably exceeds what would result from Hisinger's analysis of the chloride of cerium. It is obvious from this that Hisinger's results cannot be adopted till they are confirmed by new and more accurate experiments.

then the atomic weight of peroxide of cerium will be 7·75, and the constitution and atomic weight of cerium and its oxides will be

	Cerium.	Oxygen.	Atomic weight.
Cerium	. . . . .	.	6·25
Protoxide	1 atom +	1 atom	7·25
Peroxide	1 atom +	1½ atom	7·75

II. There are two chlorides of cerium; but they have not hitherto been very carefully examined. The protochloride is obtained when the oxides of cerium are digested in muriatic acid till the solution becomes colourless. It crystallizes with difficulty in 4-sided prisms. It deliquesces in the air; is very soluble in water and also in alcohol, and the alcoholic solution burns with a yellow-coloured flame.

The perchloride is a reddish yellow solution, which gelatinizes by cautious evaporation. It does not crystallize, and when heated is gradually converted into protochloride.

III. Nothing is known respecting the bromide and iodide of cerium. Nor is any thing known about the compounds which it may be capable of forming with hydrogen and azote.

IV. From the experiments of Laugier, it appears capable of combining with carbon. He obtained the carburet by heating protoxide of cerium, made into a paste with oil, surrounded with charcoal in a retort. The carburet was a black matter which took fire spontaneously when exposed to the air.[*]

V. No attempts have been made to combine cerium with boron or silicon.

VI. When a stick of phosphorus was put into a solution of cerium in muriatic acid, and kept for some days on a stove, the bottom and sides of the vessel were covered with a white precipitate, and the phosphorus was covered with a hard brown crust, which was tenacious, and shone in the dark. When heated it took fire, and left a small quantity of oxide of cerium. But this experiment did not succeed when repeated.[†]

VII. For every thing known respecting the sulphuret of cerium we are indebted to Mosander. It may be prepared in two different ways. 1. By passing the vapour of bisulphuret of carbon over oxide of cerium heated to redness in a porcelain tube. The sulphuret obtained in this way is light and porous, and similar to red lead in colour. It is not altered by exposure to the air, nor by water. 2. When oxide of cerium is mixed with *alkaline hepar* in great excess, and exposed to a white

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[*] Ann. de Chim. lxxxix. 317.

[†] Hisinger and Berzelius, Ann. de Chim. liv. 46.

heat in a covered crucible and the hepar afterwards washed out
with water, a sulphuret of cerium remains in brilliant scales like mosaic gold in appearance. Both of these preparations are soluble in acids with the evolution of sulphuretted hydrogen gas. Sulphuret of cerium, according to Mosander, is composed of

Sulphur	. .	26 or 2
Cerium	. .	74 or 5·7
		———
		100*

If this analysis be accurate, and the compound examined a protosulphuret it would follow from it that the atomic weight of cerium is 5·7. This number approaches much nearer the determination of Hisinger than mine. But we must abstain from drawing conclusions till Mosander has laid his analysis before the public.

None of the combinations of cerium with selenium or the metals have been hitherto subjected to examination.

SECTION V.—OF ZIRCONIUM.

Among the precious stones which come from the island of Ceylon, there is one called *jargon*, or *zircon*, which is possessed of the following properties:

Its colour is various; gray, greenish-white, yellowish, reddish-brown, and violet. It is often crystallized, either in rightangular quadrangular prisms surmounted with pyramids, or octahedrons consisting of double quadrangular pyramids. It has generally a good deal of lustre, at least internally. It is mostly semitransparent. Its hardness is inferior to that of sapphyr; but greater than that of spinell: its specific gravity from 4·416 to 4·7.†

It loses scarcely any of its weight in a melting heat; for Klaproth, who analyzed it in 1789, found that 300 grains, after remaining in it for an hour and a half, were only ¼th of a grain lighter than at first.‡ Neither was it attacked either by muriatic or sulphuric acid, even when assisted by heat. At last, by calcining it with a large quantity of soda, he dissolved it in muriatic acid, and found that 100 parts of it contained 31·5 of silica, 0·5 of a mixture of nickel and iron, and 68 of a new earth, possessed of peculiar properties, which has received the name of *zirconia*, from the mineral in which it was detected.

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* Ann. de Chim. et de Phys. xxxiii. 109. † Kirwan's Miner. i. 333.
‡ Jour. de Phys. xxxvi. 180.

Chap. III.

Owing probably to the scarcity of the zircon, nobody attempted to repeat the analysis of Klaproth, or to verify his discovery. In 1795 he published his analysis of the *hyacinth*, another mineral from the same island, in which he also detected a large proportion of zirconia, expressing his hopes that it would induce chemists to turn their attention to the subject.* This analysis induced Guyton Morveau, in 1796, to examine the hyacinths of Expailly in France. They proved similar to the hyacinths of Ceylon, and contained the proportion of zirconia indicated by Klaproth.† These experiments were soon after repeated, and the nature of the new earth still further examined by Vauquelin.‡

Zirconia.

Zirconia has hitherto been found only in the zircon and hyacinth, and in three other minerals called sillimanite, eudyalite, and polymignite. It may be obtained pure, by the following process: Reduce the mineral to powder, mix it with thrice its weight of potash, and fuse it in a crucible. Wash the mass in pure water till the whole of the potash is extracted; then dissolve the residuum as far as possible in diluted muriatic acid. Boil the solution to precipitate any silica which may have been dissolved; then filter and add a quantity of potash. The zirconia precipitates in the state of a fine powder.

Berzelius succeeded in depriving zirconia of its oxygen, and obtaining the base in an isolated state. To this base he has given the name of *zirconium.*§ His process was as follows:

Zirconium.

The double salt called *potash-fluate of zirconia* ‖ is reduced to powder and heated to drive off all its water of crystallization. It is then mixed in an iron tube with potassium, the two substances being introduced in alternate layers into the tube, it is heated sufficiently to melt the potassium, then the two substances are well mixed by means of an iron wire. It is then shut and heated over a spirit of wine lamp till it begin to get red hot. The potassium deprives the zirconium of its oxygen, and the whole is converted into fluate of potash and zirconium. When cold it is thrown into water; the fluate of potash dissolves, and the zirconium falls to the bottom in the state of a black powder. It must be well washed and dried.

Properties.

Zirconium thus obtained has a close resemblance to charcoal powder. Though rubbed by a burnisher it does not acquire

* Beitrage, i. 231.   † Ann. de Chim. xxi. 72.
‡ Ann. de Chim. xxxii. 158, and Jour. de Min. An. v. 97.
§ Kongl. Vetens. Acad. Handl. 1824, p. 295.
‖ This salt will be described in a subsequent part of this work.

the metallic lustre. It is almost always mixed with some hydrate of zirconia, which causes it to burn when gently heated. Berzelius recommends as the best way to get rid of that hydrate to put it into dilute muriatic acid, and leave it for 6 or 8 hours at the temperature of about 100°. The acid gradually dissolves the hydrate without acting sensibly on the zirconium. The zirconium thus obtained is to be washed, first in a solution of sal ammoniac and afterwards in alcohol. For when water is employed the zirconium passes along with it through the filter.

When zirconium is thus purified it has some resemblance to plumbago in appearance; being composed of brilliant scales. It is a non-conductor of electricity. When heated in hydrogen gas or in vacuo it is not altered. It does not fuse even in a strong heat. When heated in the open air it takes fire long before it is red-hot, and burns quietly, being converted into zirconia which is perfectly white. When it contains hydrate of zirconia it burns in an instant with a kind of explosion, which throws every thing out of the tube. When mixed with chlorate of potash it takes fire when violently struck; but burns without detonating. In fused nitre it does not burn at a heat below redness. When mixed with carbonate of potash it burns at the expense of the carbonic acid with a feeble disengagement of light. It burns also in melted borax, in consequence of the water which the salt retains. For the same reason it burns when heated in the alkaline hydrates.

It is not acted on at the ordinary temperature of the atmosphere by sulphuric or muriatic acids. Even when long boiled in these acids the action is very small. Neither nitric acid nor aqua regia is capable of dissolving it. But it dissolves readily in fluoric acid with disengagement of hydrogen gas. A mixture of fluoric and nitric acids dissolves it with great rapidity. It does not dissolve in caustic alkaline leys.

II. We know only one compound which it is capable of forming with oxygen; namely, *zirconia*.

This substance is usually obtained by decomposing the hyacinths of Expailly. If we heat these crystals to redness, and choose those only for our purpose which become transparent and colourless, the zirconia is exempt from iron. But if we take coloured crystals we obtain the zirconia contaminated with peroxide of iron. This oxide of iron may be removed by various processes. 1. If we dissolve the impure zirconia in muriatic acid and evaporate the solution till it be reduced to

the consistence of a paste, and then wash this paste with concentrated muriatic acid till it has dissolved all the iron, the residue will consist of a solution of pure zirconia in muriatic acid. From this pure salt the zirconia may be thrown down by ammonia, and calcined. This process was contrived by Chevreul.* 2. The impure zirconia thrown down by ammonia is well washed, and then boiled in an aqueous solution of oxalic acid till the whole iron is dissolved. What remains, after being well washed, is oxalate of zirconia. When calcined it leaves the zirconia in a state of purity. This process was contrived by Messrs. Dubois and Silveira.† 3. A saturated solution of sulphate of potash is poured into the neutral solution of zirconia. This salt deprives the zirconia of a portion of its acid, and throws it down in the state of an insoluble subsalt. When washed and digested in hydrate of potash or soda, pure zirconia is obtained. This process was contrived by Berzelius.‡

Properties.   Zirconia, thus prepared, has the form of a fine white powder, which feels somewhat harsh when rubbed between the fingers. It has neither taste nor odour. It is infusible before the blowpipe; but when heated violently in a charcoal crucible it undergoes a kind of imperfect fusion, acquires a gray colour, and something of the appearance of porcelain. In this state it is very hard, its specific gravity is 4·3, and it is no longer soluble in acids. Zirconia is insoluble in water; but it has a considerable affinity for that liquid. When dried slowly, after being precipitated from a solution, it retains about the third of its weight of water, and assumes a grayish yellow colour, and a certain degree of semi-transparency, which gives it some resemblance to common glue. It is insoluble in liquid alkalies, neither can it be fused along with them by means of heat; but it is soluble in alkaline carbonates.

After ignition, zirconia is insoluble in acids, except concentrated sulphuric acid, by digestion in which it may be dissolved. It recovers its solubility likewise, when ignited with potash. The hydrate of zirconia (in which state it is procured when precipitated from its acid solutions by ammonia, and dried without artificial heat,) is a white, bulky, semigelatinous matter, which dissolves readily in acids while moist, but after being dried its solution goes on very slowly. It contracts

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* Ann. de Chim. et de Phys. xiii. 245.   † Ibid. xiv. 110.
‡ *Traité de Chimie,* ii. 387.

much in drying. When heated it begins to glow like a live coal when the temperature is raised nearly to redness. This hydrate dissolves in small quantity and very slowly in carbonate of ammonia. It is insoluble in the fixed alkaline carbonates. But if we precipitate a salt of zirconia by carbonate of potash, and add an excess of this carbonate, the precipitate redissolves. The experiment succeeds still better with the bicarbonate of potash than with the carbonate.

• The only experiments hitherto made to determine the atomic weight of zirconia are those of Berzelius. He found neutral sulphate of zirconia composed of

Sulphuric acid	. .	• 100 or 5
Zirconia	. . .	75·853 or 3·7926

Now if this salt be composed of an atom of each constituent, it is obvious that the atomic weight of zirconia is 3·7926.*

He attempted to analyze the hydrate of zirconia, dried at the temperature of 140°; but its tendency to absorb moisture after ignition was so great, that he succeeded but imperfectly. The greatest quantity of water which he found united with 100 zirconia was 15·4. Now if we were to consider this hydrate as a compound of 2 atoms zirconia to 1 of water, the atomic weight of zirconia would be 3·65. But no confidence can be put in this result for very obvious reasons.

I attempted to determine the atomic weight of zirconia by a rigid analysis of the pure hyacinth of Expailly. The result of the analysis was,

Silica	• . . •	33·32
Zirconia	. .	66·00
		————
		•99·32

But here the loss, amounting to 0·68 per cent. destroys the consequence which might otherwise be drawn from this analysis. If the loss be supposed to fall proportionally on the two constituents, and if the mineral be a simple silicate of zirconia, the atomic weight of zirconia would be 3·96.

Berzelius analyzed the same mineral, and obtained

Silica	. .	33·48
Zirconia	. .	67·16
		————
		100·64†

But here there is an excess of 0·64 per cent. which gives to it

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* Kongl. Vet. Acad. Handl. 1824, p. 302.   † Ibid. p. 306.

the same uncertainty as my deficiency. These numbers give 4·011 for the atomic weight of zirconia.

I think it not improbable, from these analyses, that the atomic weight of this substance may ultimately turn out to be 4. Meanwhile the analysis of the sulphate of zirconia by Berzelius, which must be very near the truth, gives us nearly the number 3·75 as the atomic weight. If zirconia be a compound of

1 atom zirconium	. .	2·75
1 atom oxygen	. .	1
		———
		3·75

then 2·75 must be the atomic weight of zirconium.

Chloride.   III. When zirconium is heated in chlorine gas it takes fire, and is converted into a white fixed matter, which is chloride of zirconium.

IV. Nothing is known respecting the combination of zirconium with bromine and iodine. Nor has it been ascertained whether it unites with hydrogen and azote.

Carburet.   V. When zirconium is obtained by means of potassium, containing carbon, it seems to be in the state of a carburet. For when digested in muriatic acid it gives out a smell similar to that of cast-iron, when so treated. When calcined, the zirconia obtained is gray, and it is extremely difficult to burn out the carbon.*

VI. Nothing is known respecting the boret, silicet, or phosphuret of zirconium.

Sulphuret.   VII. Sulphuret of zirconium is obtained when zirconium and sulphur are heated in vacuo, or surrounded with hydrogen gas. At the instant of combination a feeble light is evolved. This sulphuret is a powder of a deep brown colour, which does not acquire lustre under the burnisher. It is insoluble in sulphuric, nitric, and muriatic acids. Aqua regia dissolves it slowly at a boiling heat. Fluoric acid dissolves it rapidly, while sulphuretted hydrogen gas is given out. It is not dissolved by caustic potash. When fused with hydrate of potash we obtain sulphuret of potassium and zirconia.†

VIII. Nothing is known respecting the seleniet of zirconium; nor have any experiments been made to determine whether it be capable of combining with the metals.

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* Berzelius.   † Ibid.

SECTION VI.—OF THORIUM.

During Berzelius's analytical experiments on *gadolinite* in 1815, he obtained a small quantity of a white matter, which possessed peculiar properties, and to which he gave the name of *thorina*, considering it as the oxide of a new metal.   He afterwards ascertained that this supposed new earth was merely a *phosphate of yttria.** But, in 1828, he received from Professor Esmark, of Christiania, in Norway, a black mineral like obsidian, and having a specific gravity of 4·63.   To this mineral Berzelius gave the name of *thorite*.   It was discovered in syenite in the Isle of Löv-ön, near Brevig, in Norway, and is very scarce.   This mineral Berzelius subjected to analysis, and he found it composed of the following substances:

Thorina, ...	57·91
Lime, ...	2·58
Peroxide of iron, ...	3·40
Deutoxide of manganese, . .	2·39
Magnesia, ...	0·36
Peroxide of uranium, . . .	1·61
Protoxide of lead, . . .	0·80
Oxide of tin, ...	0·01
Silica, ...	18·98
Water, ...	9·50
Potash, ...	0·14
Soda, ...	0·10
Alumina, ...	0·06
Undecomposed matter, . . .	1·70
	————
	99.54†

To obtain thorina from this mineral it was reduced to powder, and digested in muriatic acid.   It became yellow, and gave out chlorine, and finally dissolved.   It was evaporated to dryness and redissolved in muriatic acid to get rid of the silica. The muriatic acid solution was precipitated by caustic ammonia, which precipitated the thorina, still contaminated by various impurities.   While still moist it was dissolved in muriatic acid.   Through this solution a current of sulphuretted hydrogen gas was passed, which threw down a little tin and lead. It was then evaporated to dryness by a gentle heat to get rid

* Kong. Vet. Acad. Handl., 1824, p. 318.
† Poggendorf's Annalen, xvi. 387.

of a little silica, which it still contained. The new solution was precipitated by caustic potash added in excess, and boiled with it, to dissolve a little alumina, which was mixed with the thorina. The new precipitate, thus freed from silica, was dissolved in muriatic acid, and the solution being neutralized by caustic ammonia, as much sulphate of potash was added to it as it was capable of dissolving. A fine white powder fell, which was collected on the filter and washed with a saturated solution of sulphate of potash. It was now dissolved in boiling water, and the solution being mixed with caustic potash, thorina was thrown down in the state of a white powder. It was washed and dried, and was pure, with the exception of a small quantity of oxide of manganese, which it was found impossible to separate.

Thorium. When thorina is mixed with charcoal powder, and heated to redness in a porcelain tube, while a current of dry chlorine is made to pass over it, chloride of thorium is obtained. When this chloride is heated with potassium, in a platinum crucible, or a glass tube, a slight detonation takes place, and heat, but no light, is evolved. A dark gray matter is obtained. When washed with water, a little hydrogen gas is given out, the chloride of potassium dissolves, and the thorium is left in a powder, having an iron gray colour, and metallic lustre. Like aluminum, it appears to be malleable. It is not oxidized by water, even when assisted by heat. When gently heated in the open air, it takes fire and burns with very great splendour, being converted into thorina. The earth thus formed is snow white, and exhibits no traces of fusion, notwithstanding the very high temperature during the combustion.

When thorium is put into dilute sulphuric acid, a strong effervescence, with the disengagement of hydrogen gas, takes place at first; but this soon stops, even though the liquid be heated. Indeed, so slight is the action of dilute sulphuric acid on thorium, that we may employ that liquid to free it from the remains of thorina, with which it may be mixed. Nitric acid acts upon thorium with still less energy than sulphuric acid. But muriatic acid dissolves it rapidly with the evolution of hydrogen gas, at least if we assist the action by a gentle heat. Thorium is not acted on by the caustic alkalies.

Oxide, or thorina. II. The only compound which thorium seems capable of forming with oxygen is thorina. To obtain this substance in the state of a hydrate, we have only to add caustic potash to the solution of thorina in an acid.

Hydrate of thorina is gelatinous, is speedily deposited, and contracts much while drying. When dried in the open air it absorbs carbonic acid, it ought therefore to be dried in vacuo, by means of sulphuric acid. While moist it dissolves readily in acids, but it is much less soluble when dry. The salts which it forms have a styptic taste. This hydrate is insoluble in the caustic alkalies; but it dissolves in the carbonates, and the solubility increases with the concentration of these alkaline Solutions. It is more soluble in cold than in hot carbonate of ammonia. Ammonia does not precipitate thorina from a saturated solution in carbonate of ammonia, as it does zirconia. When strongly heated this hydrate gives out its water, and the anhydrous thorina obtained is very hard and difficultly reducible to powder. In that state it is soluble in no acid except the sulphuric. To obtain a solution, the earth reduced to a fine powder, must be digested for a long time in sulphuric acid, diluted with half its weight of water. The excess of acid is then driven off, and the saline mass dissolves slowly in water. It is not rendered soluble in acids by calcining it with a caustic or carbonated alkali. When the alkali is extracted after such a calcination, the thorina cannot be washed with pure water, for it forms with it a milky liquid, which passes through the filter.

Thorina is distinguished from the other earths by the fol- lowing properties:

1. Its sulphate is precipitated from its solution by raising it to a boiling temperature, and dissolves again, though slowly, in cold water. This property is peculiar to thorina.

2. It is insoluble in caustic alkaline leys, which distinguishes it from alumina and glucina.

3. It forms, with potash, a double sulphate, which is soluble in water; but insoluble in a saturated solution of sulphate of potash. This distinguishes it from yttria.

4. Zirconia forms a similar double sulphate with potash; but it is almost wholly insoluble in cold water. This distinguishes it from thorina. Besides, the salts of thorina are precipitated by prussiate of potash, which is not the case with the salts of zirconia.

5. From the protoxide of cerium it is distinguished by not becoming red brown, but continuing white when it is calcined. And by not forming a coloured bead before the blowpipe either with borax or with biphosphate of soda.

Berzelius, in order to determine the atomic weight of tho-

rina, made two successive analyses of the sulphate, which gave the following results :

	First.	Second.
Sulphuric acid,	5	5
Thorina,	8·46	8·33

By another analysis, the atomic weight came out 8·513. We cannot err much, therefore, if we fix upon 8·5 as the atomic weight of thorina. There is reason, from analogy, to conclude that thorina is a compound of

1 atom thorium,	7·5
1 atom oxygen,	1
	———
	8·5

On that supposition the atomic weight of thorium will be 7·5.

The hydrate of thorina is a compound of

1 atom thorina,	8·5
1 atom water,	1·125

Chloride.   III. Chloride of thorium is formed by the process described in the beginning of this section. Berzelius has given no account of its properties. Nor has it been analyzed. But there can be no doubt, from analogy, that it is a compound of

1 atom chlorine,	4·5
1 atom thorium,	7·5
	———
	12

so that its atomic weight must be 12.

IV. No experiments have been made to determine the nature of the bromide and iodide of thorium. Nor do we know whether it forms compounds with hydrogen, azote, carbon, boron, and silicon.

Phosphuret.   V. The *phosphuret* is formed when thorium is heated in the vapour of phosphorus. The composition is accompanied by the evolution of light. The phosphuret has a gray colour, and the metallic lustre, and has some resemblance to plumbago. It is not altered by water; but when heated it takes fire, and is converted into phosphate.

Sulphuret.   VI. *Sulphuret* of thorium is formed when a mixture of the two constituents is heated in a close vessel, and brilliant combustion accompanies the combination. The sulphuret is brown, acquires brilliancy when burnished, but never assumes the metallic lustre. When heated in hydrogen gas it undergoes no alteration. When heated in the open air the sulphur

sublimes, and the thorium is converted into thorina; it is scarcely acted on by sulphuric, nitric, or muriatic acid, even when the action is assisted by heat. Aqua regia dissolves it completely by the assistance of heat, and converts it into sulphate of thorina.

VII. Nothing is known respecting the seleniet of thorium. Nor has any attempt been made to alloy it with other metals.

FAMILY III. DIFFICULTLY FUSIBLE BASES.

The four metals which constitute this family will be described in the four following sections.

SECTION I.—OF IRON.

Iron, the most abundant and most useful of all the metals, History. was neither known so early, nor wrought so easily, as gold, silver, and copper. For its discovery we must have recourse to the nations of the east, among whom, indeed, almost all the arts and sciences first sprung up. The writings of Moses (who was born about 1635 years before Christ) furnish us with the amplest proof at how early a period it was known in Egypt and Phœnicia. He mentions furnaces for working iron* ores from which it was extracted :† and tells us, that swords,‡ knives,§ axes,‖ and tools for cutting stone,¶ were then made of that metal. How many ages before the birth of Moses iron must have been discovered in these countries, we may perhaps conceive, if we reflect, that the knowledge of iron was brought over from Phrygia to Greece by the Dactyli,** who settled in Crete during the reign of Minos I. about 1431 years before Christ; yet during the Trojan war, which happened 200 years after that period, iron was in such high estimation, that Achilles proposed a ball of it as one of his prizes during the games which he celebrated in honour of Patroclus. At that period none of their weapons were formed of iron. Now if the Greeks in 200 years had made so little progress in an art which they learned from others, how long must it have taken the Egyptians, Phrygians, Chalybes, or whatever nation first discovered the art of working iron, to have made that progress in it which we find they had done in the days of Moses?

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* Deut. iv. 20.   † Ibid. viii. 9.   ‡ Numb. xxxv. 16.
§ Levit. i. 17.   ‖ Deut. xviii. 5.   ¶ Ibid. xxvii. 5.
** Hesiod, as quoted by Pliny, lib. vii. c. 57.

I. Iron is of a gray colour; it is very rarely found in the metallic state; but the ores of it abound in almost every part of the earth. Forty-seven different species of iron ores have been described and characterized by mineralogists. But as far as metallurgy is concerned there are only two species or three at most from which the prodigious quantity of iron that occurs in commerce is extracted. These are, 1st, *magnetic iron ore*, which occurs in great abundance in Sweden and the north of Europe. It is a heavy mineral, having the metallic lustre, and being attracted by the magnet, and frequently magnetic. It is a compound of

1 atom protoxide of iron,	.	.	4·5
2 atoms peroxide of iron,	.	.	10
			14·5

or it consists of

Iron,	.	.	.	.	.	10·5
Oxygen,	.	.	.	.	.	4
						14·5

It is from this ore that the Swedish and Russian iron is obtained.

2. The ore from which the iron smelted in Great Britain is obtained is a *carbonate of iron*, which constitutes either beds in the coal formation, or exists in detached nodules in the slate clay which constitutes one of the most abundant of the beds in the coal formation. This ore is lighter than magnetic iron ore. Its colour is black or brown, or red, or gray, or even blue, and when exposed to a red heat it loses about the third part of its weight. It is composed of

1 atom carbonic acid,	.	.	2·75
1 atom protoxide of iron,	.	.	4·5
			7·25

So that the greatest quantity of iron ever contained in 100 parts of this ore is 48·27 parts; whereas 100 parts of pure magnetic iron ore contain 72·41 parts of iron. Indeed the quantity of iron contained in the carbonate is seldom so much as 48 per cent.; because it is hardly ever pure, being mixed with clay, lime, and even coal, in greater or smaller proportion. On that account it is usually distinguished among mineralogists by the name of *clay iron ore*. It has, however, the great advantage of occurring along with or near the fuel which is to be

employed in smelting it, and the processes requisite for extract- ing iron from it are, comparatively speaking, easy.

Bog iron ore and hematite or perhydrate of iron, and also the anhydrous peroxide or oligiste iron ore, are sometimes. also used as ores from which iron is, extracted, but rarely if ever in this country.

The smelting of iron in this country, to the prodigious extent Extent of the manufacture to which it is now carried, is comparatively recent, and can of iron. scarcely be dated farther back than 50 years. It seems to have owed its commencement to the armed neutrality entered into by the Russians, Swedes, and Danes towards the end of the American revolutionary war. The quantity now annually smelted exceeds 600,000 tons, and the price has sunk to little more than 5 pounds per ton. The consequence of this low price has been an increased consumption of iron beyond all anticipation, to the great benefit of the country and all the branches of trade and manufacture. The two great foci of the iron manufacture in Great Britain, are the neighbourhood of Swansea and the country between Wolverhampton and Dudley in Staffordshire. But a good deal is also made in Shropshire, Yorkshire, Derbyshire, North Wales, and Scotland. Many improvements have been recently introduced into the smelting processes.

The following is a short sketch of the method of smelting iron ore, practised in this country.

1st Process, *Roasting.* The ore broken into small pieces is 1. Roasting. mixed with small coal and laid to a height of 6 or 7 feet on large pieces of coal; forming a heap which is narrow, but as long as the ground will permit. The combustion is begun at one end, and allowed to proceed till it reaches the farthest extremity. The quantity of coal used in this process varies in different places according to the goodness of the coal. The most being 1 ton of coal to 5 tons of ore, and the least 1 ton of coal to 8 tons of ore. By this process the carbonic acid gas of the ore is driven off. The loss of weight varies from one-fourth to one-third, according to the goodness of the ore. In general $3\frac{1}{4}$ tons of the raw ore when roasted are reduced to $2\frac{1}{4}$ tons. From this quantity of ore about 1 ton of cast-iron is generally obtained.

2d Process, *Smelting.* This process consists in mixing the 2. Smelting. roasted ore with limestone and coke, and exposing it to a strong heat in a blast furnace.

The furnace is a kind of cone from 36 to 60 feet in height, according to the extent of the work. Its most common height

is 45 or 50 feet, of which the chimney constitutes one-fifth part. The diameter of the chimney varies from 4 to 6 feet. The undermost part of the furnace consists nearly of a square building. Then it swells out and is at its widest about one-third from the bottom, after which its dimensions gradually contract to the chimney, It is built of good fire-brick, and is double to keep in the heat.

Flux. Limestone is used as a flux to separate the clay (*alumina* and *silica*) with which the ore is always contaminated. For lime has the property of uniting with clay and melting with it into a liquid glass. The proportion of limestone varies according to the goodness of the ore. In general $2\frac{1}{4}$ tons of the roasted ore require 19 hundred weight of limestone. Or in round numbers 3 tons of unroasted ore require 1 ton of limestone.

Coking. The coal, before it can be employed for smelting iron ore, requires to be *coked*. The method of coking usually followed in the neighbourhood of Glasgow is as follows: A brick chimney is built about 5 feet high. Large pieces of coal are ranged round it and smaller farther off, till a heap is formed 15 feet in diameter and about 4 feet high. The heap is then covered with small coal or ashes. The fire is kindled at the chimney; openings being made here and there and again shut to regulate the combustion. It is allowed to continue about 24 hours, and is at last put out by throwing water on the heap. By this process the coal in our neighbourhood loses about half its weight. The same remark applies to the Staffordshire coal. But in Wales they use a kind of coal called *culm*, which yields 71 per cent. of coke.

About 6 tons of coal are required to make one ton of cast-iron; but the quantity varies in different places. In Scotland it was once as high as ten ton of coal for one ton of cast-iron; but of late years the quantity has been greatly reduced. The reduction was accomplished by diminishing the pressure upon the air in the cylinders which constitute the bellows that blow the furnace, from $3\frac{1}{2}$ lbs. per square inch to $1\frac{1}{2}$ lbs. In South Wales less coals are necessary than any where else on account of the goodness of the quality.

The ore, the coke, and the limestone (broken into small pieces), are introduced into the furnace, after it has been kindled, in basketfuls, and in the proportions just stated. The furnace is always kept full, and after being lighted it is never extinguished till it requires to be repaired. The blast of air is driven into the furnace from large cylinders by means of a steam-engine.

Formerly these cylinders were plunged in water, and by this means rendered air-tight, but it has been found beneficial to remove the water and keep the air dry.   By the joint action of the lime and coke the ore is freed from its impurities which melt into a liquid glass; while the iron deprived of its oxygen tumbles by its weight to the bottom of the furnace below the blast, where it accumulates in a melted state, and over which the scoriæ or glass swims in a state of fusion.

• The furnace is tapped every 24 hours, and the melted iron is allowed to run into large ingots called *pigs* in sand moulds. The scoriæ flow out after the iron and are thrown away.   By this process the iron is obtained in the state of *cast-iron.*   Of this there are three qualities distinguished by the names of No. 1, No. 2, and No. 3.   Of these No. 1. is the most valuable in the state of cast-iron, and No. 3 the least valuable.   The appearance of the scoriæ enables us to distinguish which of these three varieties of cast-iron the furnace has yielded.

The scoriæ of No. 1, are uniform in colour and appearance, glassy and feebly translucent.

The scoriæ of No. 2 are opaque, heavy, of a yellowish green colour, exhibiting bands of bluish enamel.

The scoriæ of No. 3 are black, vitreous, blebby, and give out the smell of sulphuretted hydrogen.

The quantity of cast-iron made in a given time has of late years very much increased.   A furnace from 50 to 60 feet in height yields from 60 to 70 tons of cast-iron in the week. When the Clyde Iron Works near Glasgow were first erected, the produce from two furnaces was only 15 tons per week.   At present the same two furnaces yield about 90 tons a week.   It is more difficult to obtain cast-iron of the first quality in summer than in winter.

3d Process, *Refining.*   When the cast-iron is intended to be used in the state in which it is first obtained, the object of the smelter is to form No. 1, though this is not always in his power.   But when all the iron smelted is to be converted into bar-iron, as in Wales, the cast-iron is always obtained in the state of No. 2.   The composition of the scoriæ in that case is most commonly

> 2 atoms silicate of lime,
> 1 atom silicate of alumina.

But there is usually present also some silicate of iron and silicate of magnesia.

When cast-iron is to be converted into bar-iron it undergoes

three successive processes, the first of which is called *refining*. By this process it is converted into No. 3, or *white cast-iron*. 6 pigs of cast-iron are put at once into the refining furnace, and covered with coke above and below. The whole is fused and kept in that state for 24 hours. During this process a good deal of carbonic oxide gas is given out, as is obvious from the blue flame. It is then drawn from the furnace and cast into a cake 10 feet long, 3 feet wide, and two and a half inches thick. It is then cooled with water. In this state it is white and very hard. Its fracture is fibrous or radiated, and it is often filled with spherical cavities. The scoriæ from this process are obviously derived from impurities in the cast-iron and from the ashes of the coke. They are black, metallic, often fibrous and crystallized. A specimen of these scoriæ analyzed by Berthier was found to be a compound of

<div align="center">

1　atom phosphate of alumina,

$8\frac{1}{2}$ atoms silicate of iron.

</div>

The loss sustained during this process varies from 12 to 17 per cent. For every ton of cast-iron refined, about 2 or $2\frac{1}{2}$ tons of coke are employed. By this process the iron is freed from scoriæ, and brought to the state of white cast-iron. When phosphoric acid is present, it appears from the analysis of the scoriæ that it is got rid of by this process.

4. Puddling.　　　4th Process, *Puddling*. This process, to which the extent of the manufacture of iron is altogether owing, was contrived by Mr. Cort, of Gosport, about the year 1785. It lasts about two hours and a half. The white cast-iron, or *fine metal*, of the last process, is put into a reverberatory furnace, in which it is arranged round the edges. Heat is supplied by the flame of pit-coal which is made to play upon it. The metal softens; it is stirred and gradually falls to pieces. The fire is then lowered, and the stirring continued till the metal is reduced to the consistence of sand. In this state much carbonic oxide is given out, and when the evolution of this gas is perceived to be at an end the fire is raised and the stirring continued. The particles begin gradually to cohere together, or to *work heavy*, as the workmen term it. The operator now collects the iron into balls, and raises the heat to a welding temperature. It is now taken out of the furnace, and either hammered or rolled into bars; during which process the scoriæ are squeezed out and the iron left in a state of purity.

The quantity of coal used in this process varies in different places. In Wales 10 tons of coals are consumed in puddling

9 tons of metal. The loss of weight sustained by the iron during the process varies from 8 to 10 per cent. The scoriæ formed are black, very heavy, and sometimes crystallized, and the shape of the crystals is that of pyroxene, according to the determination of M. Mitcherlich. * These scoriæ are not always identical in their composition; but most commonly they consist of sesquisilicate of iron.

5th Process, *Welding.* The iron after being drawn out into bars after the puddling is called *mill-bar-iron.* Its quality is still so bad that it is scarcely fit for any purpose. To improve it the bars are heated red hot and cut in pieces by scissors. Four of these pieces are placed one above another in a reheating furnace. In half an hour they begin to adhere. They are then drawn out into bars by means of a cylinder. When very good iron is required, as for anchors, this welding process is repeated.

Scoriæ appear during this process. They are lamellar and steel-gray. In their cavities they contain crystals of pyroxene. They consist chiefly of sesquisilicate of iron with a little sesquisilicate of alumina.

The iron made in Great Britain is recommended by its cheapness, and answers very well for most purposes. But the purest iron is the Swedish, and the Russian, known by the name of *old sable.* But iron is never absolutely free from foreign matter. I attempted to prepare some by reducing some pure peroxide of iron, which I had prepared, to the metallic state by passing a current of dry hydrogen gas over it, while heated in a porcelain tube. The process is easy; but I was disappointed in the result. For I found that as soon as my pure iron was exposed to the air it took fire of its own accord, and was converted on the spot into red oxide.*

I. Iron has a grayish colour and the metallic lustre, and, when polished, has a great deal of brilliancy. It has a styptic taste, and emits a smell when rubbed.

Its hardness exceeds most of the metals; and it may be rendered harder than most bodies when converted into steel. Its specific gravity is 7·843 by my trials.†

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* From the observations of Stromeyer it would appear that this property is owing to a small quantity of the protoxide of iron remaining in the mass unreduced. For he found iron completely reduced by hydrogen gas not to have the property of burning spontaneously when exposed to the air. See Poggendorf's Annalen, vi. 472.

† Dr. Shaw states the specific gravity of iron at 7·645. Shaw's Boyle, ii.

It is attracted by the magnet or loadstone, and is itself the substance which constitutes the loadstone. But when iron is perfectly pure, it retains the magnetic virtue for a very short time.

It is malleable in every temperature, and its malleability increases in proportion as the temperature augments; but it cannot be hammered out nearly so thin as gold or silver, or even copper. Its ductility, however, is more perfect; for it may be drawn out into wire as fine, at least, as a human hair. Its tenacity is such, that an iron wire, 0·078 of an inch in diameter, is capable of supporting 449·34 lbs. avoirdupois without breaking.* When iron is drawn out into wire its strength is $1\frac{1}{2}$ times greater than that of hammered iron. Iron, according to the experiments of Navier, begins to be elongated, and to alter its shape, when subjected to a force amounting to $\frac{2}{3}$ds of that which is capable of breaking it or bursting it.† It is obvious therefore that iron boilers should never be exposed to so much as $\frac{2}{3}$ds of the force which is capable of bursting them.

When heated to about 158° Wedgewood, as Sir George M'Kenzie has ascertained,‡ it melts. This temperature being nearly the highest to which it can be raised, it has been impossible to ascertain the point at which this melted metal begins to boil and to evaporate. Iron is capable of crystallizing, and the shape of the crystals is the regular octahedron. This also is the shape of the crystals of magnetic iron ore.

Combination
with oxygen.   II. When exposed to the air, its surface is soon tarnished, and it is gradually changed into a brown or red powder, well known under the name of *rust*. This change takes place more rapidly if the atmosphere be moist. It is occasioned by the gradual combination of the iron with the oxygen of the atmosphere, for which it has a strong affinity.

Iron decomposes water at the common temperature of the

---

345. Brisson at 7·788. Mr. Hatchett found a specimen 7·700. On the *Alloys of Gold*, p. 66. Swedenburgh states it at 7·817. According to Muschenbroeck, hammered iron softened by heat is of the specific gravity 7·600; the same hammered hot, becomes 7·7633; and the same hammered cold, becomes 7·875. Wasserberg, i. 168.

* Rennie, Phil. Trans. 1818, p. 126. English iron only supports a weight 348·38 lbs. See Annals of Philosophy, vii. 320. Navier found that an iron wire 1 milli-metre (0.03937 inch) in diameter was broken by a weight of 90 lbs. avoirdupois. Ann. de Chim. et de Phys. xxxiii. 225.

† Ann. de Chim. et de Phys. xxxiii. 225.

‡ Nicholson's 4to Jour. iv. 109.

air slowly, and almost imperceptibly. But at a red heat the decomposition goes on with rapidity; pure hydrogen gas being evolved in abundance. It is even capable of decomposing potassium when assisted by a sufficiently high temperature.* When iron wire, having a little cotton tied to its extremity, is plunged into oxygen gas while the cotton is in flames, it takes fire and burns with great brilliancy.

As far as is known at present, iron combines with only two proportions of oxygen, and forms two oxides, the *protoxide* and the *peroxide.* The protoxide has a dark blue colour; the peroxide is red.

1. The protoxide of iron is formed whenever iron is dis- Protoxide. solved in diluted sulphuric or muriatic acids. It constitutes the basis of green vitriol, and is easily thrown down from the solution of that salt in water by an alkali. It falls in the state of light green flocks which gradually collect at the bottom of the vessel and assume a black colour. The tendency of this oxide to absorb oxygen from the atmosphere is so great that it is out of our power to collect it. And indeed it was unknown in a state of purity till Stromeyer pointed out a method of preparing it. He formed it by passing a current of dry hydrogen gas over peroxide of iron at a temperature considerably under that at which it would be reduced to the metallic state. Protoxide of iron thus obtained has a deep blackish blue colour, appearing by reflected light almost black. It is to this protoxide that iron slag owes its blue colour. The protoxide of iron thus prepared burns with great splendour whenever it comes in contact with the air, and is converted into peroxide. It cannot therefore be preserved.*

Various attempts have been made to determine the composition of this oxide by analysis. The experiment, however, is attended with a good deal of difficulty in consequence of the great tendency which protoxide of iron has to unite with oxygen. According to Berzelius this oxide is a compound of

Iron,	.	.	3·39213
Oxygen,	.	.	1
			4·39213

But Stromeyer has shown that his estimate of the quantity of oxygen is 0·51 per cent. too high. By a careful analysis

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* *Poggendorf's Annalen, vi.* 474.

of sulphate of iron I have ascertained that the atomic weight of the protoxide is 4·5, and as it is obviously a compound of

$$
\begin{array}{lll}
\text{1 atom iron,} & . & . & 3\text{·}5 \\
\text{1 atom oxygen,} & . & . & 1 \\
\hline
& & & 4\text{·}5
\end{array}
$$

it is evident that the atomic weight of iron must be 3·5. This determination is corroborated by the experiments of Gay-Lussac, who found protoxide of iron a compound of

$$
\begin{array}{lll}
\text{Iron,} & . & . & 3\text{·}53 \\
\text{Oxygen,} & . & . & 1\text{·} \\
\hline
& & & 4\text{·}53*
\end{array}
$$

What has been called the black oxide of iron is a mixture of protoxide and peroxide in various proportions. The limits would appear to be a compound of 1 atom protoxide and 2 atoms peroxide. This constitutes what Gay-Lussac has viewed as a peculiar oxide of iron. But that it is only a compound of the two oxides seems evident from this, that if we dissolve it in sulphuric acid we obtain two different sulphates, namely, the protosulphate and persulphate, which are separable from each other by alcohol. Magnetic iron ore is a compound of this nature. So is *finery cinder*, or the matter squeezed out from iron during the process of converting cast into bar-iron. Such also Gay-Lussac found the oxide formed when iron wire is burnt in oxygen gas; but I found the quantity of oxygen which it contained only 28 parts united to 100 of metal. It would appear from this, that its nature is not always the same.

This compound of the two oxides has been called by Berzelius *oxydum ferroso-ferricum*. When strongly heated it melts and assumes the metallic lustre. It is very brittle; and from the experiments of Berthier and Mosander it appears to vary a good deal in its composition. Berthier analyzed the scales that are formed when bars of iron are heated to whiteness and then hammered in the open air, or what we call in this country *smithy* ashes. He found them composed of

$$
\begin{array}{lll}
\text{2 atoms protoxide of iron,} & . & . & 9 \\
\text{1 atom peroxide of iron,} & . & . & 5 \\
\hline
& & & 14\dagger
\end{array}
$$

or of

| Iron, | . | . | . | . | 3·5 |
| Oxygen, | . | . | . | . | 1·166 |

Mosander found that when bars of iron were heated and allowed to cool in the open air the outer layer of scales contained more peroxide than the inner layer. The inner layer, according to him, is a compound of

3 atoms protoxide,	.	.	13·5
1 atom peroxide,	.	.	5
			———
			18·5*

or it is a compound of

| Iron, | . | . | . | . | 3·5 |
| Oxygen, | . | . | . | . | 1·125 |

While the outermost layer was a compound of

1 atom protoxide,	.	.	4·5
1 atom peroxide,	.	.	5
			———
			9·5

or of

| Iron, | . | . | . | . | 3·5 |
| Oxygen, | . | . | . | . | 1·25 |

Besides the oxides of iron, these iron scales contain always a certain portion of silica, and it appears from Mosander's analyses to the number of 6 that the composition of the scales themselves is not uniform.

Thus it appears that black oxide of iron, as it is called, is very various in its composition; but that four definite compounds of protoxide and peroxide have been obtained. These are,

	Protoxide.	Peroxide.			Atomic weight.
1.	3 atoms	+ 1 atom,	.	.	18·5
2.	2	+ 1	.	.	14
3.	1	+ 1	.	.	9·5
4.	1	+ 2	.	.	14·5

or we may represent the quantity of oxygen united in each to an atom of iron as follows :

				Atom.
1st,	composed of 3·5 iron	+ 1·125. oxygen or	$1\frac{1}{8}$
2d,	of 3·5	+ 1·166	or $1\frac{1}{6}$
3d,	of 3·5	+ 1.25	or $1\frac{1}{4}$
4th,	of 3·5	+ 1·33	or $1\frac{1}{3}$

These have been converted by the French chemists into

* Kongl. Vetens. Acad. Handl., 1825, p. 209.

so many different oxides of iron. But it is a simpler view of the subject, and more conformable with truth, to consider them as so many compounds of the two known oxides of iron in definite proportions.

Peroxide. 2. Peroxide of iron is easily obtained by dissolving iron in nitric acid, evaporating the solution to dryness, and exposing the dry mass to a heat gradually raised to redness. It may be obtained also, but not so easily, by keeping iron filings red hot in an open vessel, and triturating them continually till they are reduced to a fine powder. It is a fine red powder, destitute of taste and smell, insoluble in water, but soluble in acids, especially the muriatic acid, which is the best solvent of this oxide. After exposure to a red heat it loses much of its easy solubility in acids. To obtain it in the state of an hydrate, the best way is to throw it down from its solution in nitric acid, by means of an alkali, and after washing it thoroughly, allow it to dry in the open air. I ascertained by a careful analysis of persulphuret of iron that when 3·5 iron are converted into peroxide they become 5.* Hence it is a compound of

1 atom iron,	.	.	3·5
1½ atom oxygen,	.	.	1·5
			——
			5

Hydrated peroxides. There are two hydrates of this peroxide which occur native. The first is a dihydrate composed of

2 atoms peroxide,	.	.	10
1 atom water,	.	.	1.125
			————
			11·125

This dihydrate is red coloured, and has a fibrous structure. It is uncommon. The specimen which I subjected to analysis was found in nodules in the rocks in the neighbourhood of Gourock, a village three miles west from Greenock.

The red fibrous mineral known by the name of hematite is a hydrate of this oxide composed of

1 atom peroxide,	.	.	5
1 atom water,	.	.	1·125
			————
			6·125

Rust. Rust of iron consists chiefly of hydrated peroxide of iron.

* First Principles, i. 354.

But it is mixed also not unfrequently with a quantity of pro-
tocarbonate of iron, or of carbonic acid united to protoxide of
iron; for carbonic acid does not seem capable of uniting with
the peroxide of this metal.

Both of the oxides of iron possess the characters of alkaline
bases, and unite to acids constituting salts.

Cutting instruments of steel, after being finished, are hard-
ened by heating them to a cherry red, and then plunging them
into a cold liquid. After this hardening, it is absolutely neces-
sary to soften them a little, or to *temper* them as it is called,
in order to obtain a fine and durable edge. This is done by
heating them till some particular colour appear on their sur-
face. The usual way is to keep them in oil, heated to a par-
ticular temperature, till the requisite colours appear. Now
these colours follow one another in regular succession accord-
ing to the temperature. Between 430° and 450°, the instru-
ment assumes a very pale yellowish tinge; at 460°, the colour
is a straw yellow, and the instrument has the usual temper of
pen-knives, razors, and other fine edge tools. The colour
gradually deepens as the temperature rises higher, and at 500°
becomes a bright brownish metallic yellow. As the heat
increases, the surface is successively yellow, brown, red, and
purple, to 580°, when it becomes of a uniform deep blue, like
that of watch-springs.* The blue gradually weakens to a
water colour, which is the last shade distinguishable before the
instrument becomes red hot.† That these different shades of
colour are owing to the oxidizement of the surface becomes
evident from a mode of ornamenting sword-blades, knives, &c.
long practised in Sheffield. Flowers, and various other orna-
ments, are painted on the blade with an oily composition. It
is then subjected to the requisite heat for tempering it. The
colour of the blade is altered in every part except where it is
covered with the paint. When the paint is taken off the
ornaments appear of the natural colour of polished steel, and
of course are easily distinguishable. Sir H. Davy, in conse-
quence of a letter from Mr. Stoddart, found that when steel
is heated in hydrogen gas it does not change its colour as it
does when tempered in the usual way.‡ From these facts it
is obvious that the changes of colour are owing to the oxidize-

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* See the curious experiments of Mr. Stoddart, as related by Mr. Nichol-
son. Nicholson's 4to Jour. iv. 129.

† Lewis, Newman's Chem. p. 79.   ‡ Annals of Philosophy, i. 131.

ment of the surface of the iron. Whether the changes be owing to alterations in the thickness of the coat of oxide or to the formation of various proportions of the two oxides we have no data to determine.

Chloride.   III. Chlorine like oxygen unites to iron in two proportions, and forms a chloride and a *sesquichloride.*

Protochloride.   1. The protochloride may be formed by dissolving iron in muriatic acid, evaporating the solution to dryness, and exposing the dry mass to a red heat in such a manner as to exclude the action of air on it. It has a gray but variegated colour, and a metallic splendour. Its texture is lamellated. When heated to redness it melts, but is not volatilized. It is imperfectly soluble in water, and the solution yields crystals of green muriate of iron. It was first described by Dr. John Davy, who found its constituents 4·5 chlorine and 3·9 iron. ‘There can be no doubt that it is a compound of

| 1 atom chlorine | . | . | 4·5 |
| 1 atom iron | . | . | 3·5 |

$$\overline{8}$$

and that its atomic weight is 8.

Sesquichloride.   2. The sesquichloride of iron was first described by Sir H. Davy,* and afterwards more particularly examined by Dr. John Davy.† It may be obtained by burning iron wire in chlorine gas, or by evaporating the red muriate of iron to dryness, and heating it in a tube with a narrow orifice. It is a substance of a bright brown colour, with a lustre approaching that of iron ore from the isle of Elba. It is volatilized by a moderate heat, and forms minute brilliant crystals, the shape of which has not been determined.‘ It dissolves completely in water, and the solution constitutes red muriate of iron. According to the analysis of Dr. Davy, it is composed of 6·75 chlorine and 3·65 of iron. Now 6·75 represents $1\frac{1}{2}$ atoms chlorine. It is obvious therefore that it is a compound of

| $1\frac{1}{2}$ atom chlorine | . | . | 6·75 |
| 1 atom iron | . | . | 3·5 |

$$\overline{10\text{·}25}$$

and that its atomic weight is 10·25.

Bromide.   IV. Doubtless bromine will be found capable of combining with iron in two proportions as well as oxygen and chlorine.

* Phil. Trans. 1811, p. 23.   † Ibid. 1812, p. 181.

But hitherto only one of these compounds has been examined. When iron wire is heated to redness in a glass tube, and dry bromine vapour passed over it, the wire becomes incandescent, and fuses without the disengagement of any gas. The bromide thus formed has a yellow colour, and a lameller structure. It dissolves readily in water without communicating colour to that liquid, and the solution is precipitated light yellow by nitrate of silver. This bromide is composed of

1 atom bromine	.	.	10
1 atom iron	.	.	3·5
			13·5

and its atomic weight is 13·5.*

V. We are acquainted at present with only one *iodide* of this metal. It was first mentioned by Sir H. Davy, and afterwards was more minutely described by Gay-Lussac. It may be formed by heating iron in contact with vapour of iodine. It is a brown substance which fuses at a red heat. It dissolves in water and forms a light green solution consisting without doubt of hydriodate of iron. It has not been analyzed. But it is probably composed of one atom iodine united to one atom iron, or by weight of

Iodide.

Iodine	.	.	15·75
Iron	.	.	3·5
			19·25

VI. We do not know any compound which iron is capable of forming with hydrogen† or azote.

VII. It combines with carbon, and forms the very important compounds known by the names of *cast-iron* and *steel*; of both of which there are several modifications.

Carburets.

There are three varieties of cast-iron commonly distinguished in commerce; namely, *black cast-iron* usually called No. 1, *mottled cast-iron* called No. 2, and *white cast-iron.*

1. Black cast-iron is the softest of the three. Its specific gravity, according to my trials, varies from 6·90102 to 6·836. It is imperfectly malleable and admits of being easily turned on the lathe and filed down. It melts at a comparatively low heat. Its texture is granular. It is much used in this country for a

Black cast-iron.

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* Ann. de Chim. et de Phys. xxxiii. 331.

† In page 160 of this volume I have given my reasons for believing that iron and hydrogen are capable of combining at a certain temperature. But nothing is known respecting the nature of the compound formed.

great variety of purposes, admitting of being easily cast into all the variety of shape which is wanted.

2. Gray or mottled cast-iron is so called from the inequality of its colour. Its specific gravity, by my trials, is 7·0683. It is harder than the black variety, but soft enough to be cut, bored, and turned on the lathe. It is also much used in this country. For many purposes it is found expedient to mix No. 1 and No. 2, and fuse them together. Artillery is usually made of mottled cast-iron.

3. White cast-iron has a white colour like silver. Its texture is fibrous or crystalline, and its specific gravity 7·6849.* It is so extremely hard that it can neither be filed, bored, nor bent, and it is very apt to break when suddenly heated or cooled. It has not been applied to any useful purpose; but is always formed when cast-iron is converted into bar-iron.

I made several attempts to analyze white cast-iron, by treating it with dilute nitric acid without heat. The residue not acted on by the acid was a brown powder possessing considerable lustre. When heated to 420° it took fire and burnt with considerable lustre, leaving a red powder, which by repeated digestions in acids, and finally by fusing it with nitre, I reduced to peroxide of iron and silica. The mean of several analyses made in this way (but not exactly agreeing with each other) gave the composition of the iron

$$
\begin{array}{lr}
\text{Iron,} & 95 \\
\text{Carbon,} & 5 \\
\hline
& 100
\end{array}
$$

I reckon along with the carbon a little silicon, which varied so much in quantity in different experiments, that I could only consider it as accidental. Now this approaches very near

$$
\begin{array}{lr}
\text{4 atoms iron,} & 14 \\
\text{1 atom carbon,} & 0·75 \\
\hline
& 14·75
\end{array}
$$

I am disposed, therefore, to consider white cast-iron as essentially a compound of 4 atoms iron and 1 atom carbon, and in that case its atomic weight will be 14·75.

My experiments on black cast-iron were not so successful; but they led to the conclusion that it was a compound of

* The specimen was from Danemora.

Iron	.	.	.	93·4
Carbon	.	.	.	6·6

100

Now this comes pretty near

3 atoms iron	.	.	10·5
1 atom carbon	.	.	0·75

11·25

I am therefore disposed to consider black cast-iron as a compound of 3 atoms iron and 1 atom carbon. And if so its atomic weight will be 11·25.

But besides iron and carbon, cast-iron is never quite free from some silicon; it frequently contains also a trace of magnesium, and not rarely a little manganese; though all these constituents are so variable in point of quantity, that nothing can be asserted respecting them. I made no attempt to analyze mottled cast-iron, not having been able to procure specimens of a sufficiently decided nature to warrant the considering of them as specifically distinct from black cast-iron. It is possible that mottled cast-iron may be a compound of

$3\frac{1}{2}$ atoms iron	.	.	12·25
1 atom carbon	.	.	0·75

13

This would make it intermediate between black and white cast-iron.

STEEL is a compound of iron of the utmost consequence; Steel. because it is from it alone that all the numerous cutting instruments of so much importance to mankind are made, iron itself being too soft for this purpose. The discovery of steel is of so ancient a date that it precedes the origin of authentic history. The Greeks distinguished steel by the name of στόμωμα, and by the Romans it was called *acies*. Pliny informs us that in his time the best steel came from China, and the next best from Parthia. A manufacture of steel seems to have existed in Sweden as early as the year 1340. It is the general opinion that the process for converting iron into steel called *cementation* originated in England; but I am unacquainted with the history of the process.

Every kind of iron is not fit for being converted into steel. British iron does not answer at all. When it is to be made into steel it is necessary to leave a portion of the bar in the

state of iron, otherwise it would fly in pieces when we attempt to draw it out into bars. The iron which answers best for being converted into steel is the iron made at Danemora in Sweden from a magnetic iron ore. The whole of the produce of the Danemora mines, amounting to about 8000 tons, is imported into Britain, and converted into steel. There is also one Russian forge which yields an iron which makes very good steel. This iron is known by the name of *old sable*. The iron from all the other Russian forges is unfit for steel making.

How made. The furnace in which iron is converted into steel has the form of a large oven or arch terminating in a vent at the top. The floor of this oven is flat and level. Immediately under it there is a large arched fire-place with grates, which runs quite across from one side to the other, so as to have two doors for putting in the fuel, from the outside of the building. A number of vents or flues pass from the fire-place to different parts of the floor of the oven, and throw up their flame into it, so as to heat all parts of it equally. In the oven itself there are two large and long cases or boxes, built of good fire stone, and in these boxes the bars of iron are regularly stratified with charcoal powder, ten or twelve tons of iron being put in at once, and the box is covered on the top with a bed of sand. The heat is kept up, so that the boxes and all their contents are red-hot for eight or ten days. A bar is then drawn out and examined, and if it be found sufficiently converted into steel, the fire is drawn, and the oven allowed to cool. This process is called cementation.

Blistered steel. The bars of steel formed in this way are raised in many parts into small blisters, obviously by a gas evolved in the interior of the bar, which had pushed up by its elasticity a film of the metal. On this account the steel made by this process is usually called *blistered steel*.

Tilted steel. The bars of blistered steel are heated to redness and drawn out into smaller bars by means of a hammer driven by water or steam, and striking with great rapidity. This hammer is called a tilting hammer, on which account the small bars formed by it are called *tilted steel*. When the bars are broken in pieces and welded repeatedly, and then drawn out into bars, they get the name of *German* or *shear steel*.

Cast-steel. Steel of cementation, however carefully made, is never quite equable in its texture. But it is rendered quite so by fusing it in a crucible, and then casting it into bars. Thus treated it is called *cast-steel*, and sells at a much higher price than

common steel. The process was contrived by Mr. Huntsman of Sheffield, about the year 1750. It was kept for some time as a secret; but for many years has been generally known in this country. When steel is to be *cast*, it is made by cementation in the usual way, only the process is carried somewhat farther, so as to give the steel a whiter colour. It is then broken into small pieces, and put into a crucible of excellent fire clay, after which the mouth of the crucible is filled up with vitrifiable sand, to prevent the steel from being oxidized by the action of the air. The crucible is exposed for 5 or 6 hours to the most intense heat that can be raised; by which the steel is brought into a state of perfect fusion. It is then cast into parallelopipeds about a foot and a half in length. To fuse one ton of steel about 20 tons of coals are expended. This accounts for the high price of cast-steel when compared with that of iron, or even of common steel. Every time that cast-steel is melted it loses some of its characteristic properties, and two or three fusions render it quite useless for the purposes for which it is intended.*

The specific gravity of good blistered steel I found to be 7·823. When this steel was heated to redness, and suddenly plunged into cold water, its specific gravity was reduced to 7·747. The specific gravity of a piece of cast-steel while soft was found to be 7·8227; but when hardened by heating it red-hot and plunging it into cold water, the specific gravity was reduced to 7·7532. We see from this, that when steel is hardened its bulk is increased. Doubtless the volume which it acquired by heating it to redness is retained, the cold water solidifying the surface before the mass has had time to contract.

The colour of steel is whiter than that of iron. Its texture is granular and not hackly like that of iron. The fracture is whitish-gray, and much smoother than the fracture of iron. It is much harder and rigid than iron, nor can it be so much softened by heat without losing its tenacity and flying in pieces

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* M. Breant has shown that the steel of which the Damascus blades were made, and which was steel from Golconda, owed the peculiarity which these blades have of showing a curious waving texture on the surface, when treated with a dilute acid, to their consisting of two different compounds of iron and carbon which have separated during the cooling. It is cast-steel in which the process is carried farther than usual, and which is cooled slowly. Both common steel and cast-iron are formed, which separate during the slow cooling. The steel is rendered black by the acid, while the cast-iron remains white. This kind of steel can only be hammered at a heat above that of cherry red. Ann. de Chim. et de Phys. xxiv. 388.

under the hammer. It requires more attention to forge it well than to forge iron. Yet it is by its toughness and capability of being drawn out into bars that good steel is distinguished from bad. Steel is more readily broken by bending it than iron. If it be heated to redness and then plunged into cold water it becomes exceedingly hard, so as to be able to cut or make an impression on most other bodies. But when iron is treated in the same way its hardness is not in the least increased. When a drop of nitric acid is let fall upon a smooth surface of steel and allowed to remain on it for a few minutes, and then washed off with water, it leaves a black spot: whereas the spot formed by nitric acid on iron is whitish-green. Steel is not so easily converted into a magnet as iron; but when once converted it retains the magnetic virtue; whereas iron loses it immediately when the exciting cause is withdrawn. Steel possesses great elasticity, and from Mr. Tredgold's experiments it appears that the elastic force is sensibly the same in all states of temper.*

The first attempt to investigate the nature of steel was by Reaumur in a book which he published in 1722, entitled *L'art de convertir le fer forgé en acier, et l'art d'adoucir le fer fondu ou de faire des ouvrages de fer fondu aussi fines que de fer forgé.* He considers steel as iron impregnated with sulphureous and saline matters. The efficacy of charcoal in converting iron into steel was known, and as it was at that time the general opinion that charcoal consisted almost entirely of phlogiston, the inference drawn was, that steel differed from iron in containing a greater quantity of phlogiston. This opinion continued to prevail till Bergman in 1781, published his celebrated experiments on iron. He showed that when a given weight of cast-iron was dissolved in dilute sulphuric acid the hydrogen gas evolved varied from 38 to 43 volumes; that from the same weight of steel varied from 45 to 48 volumes; while that from the same weight of hammered iron varied from 48 to 50 volumes. Now when Bergman wrote, the hydrogen gas given out was conceived to be the phlogiston of the metal. Hence it was inferred from these experiments, that pure iron contains the *most* phlogiston, and cast-iron the least. Thus Bergman's experiments reversed the common opinion.

When these different kinds of iron were dissolved in dilute sulphuric acid there always remained a quantity of insoluble matter, which Bergman called *plumbago*, and which consisted

* Phil. Trans. 1824, p. 354.

chiefly of carbon, and when this plumbago was burnt away a little silica always remained. 100 parts of cast-iron yielded from 1 to 3·3 of this plumbago; 100 parts of steel from 0·2 to 0·8, and 100 parts of hammered iron from 0·05 to 0·2. Hence it was concluded that carbon enters as a constituent into cast-iron and steel, but not into hammered iron.

In 1786 an elaborate dissertation on the same subject by Monge, Berthollet, and Vandermonde, appeared in the Memoirs of the French Academy. They examined the experiments of Bergman and added a considerable number of their own, and drew as a final conclusion that hammered iron (if pure) consists of *iron* free from all heterogeneous matter. That steel is a combination of iron and carbon, and cast-iron a combination of iron with a still greater quantity of carbon and not free from oxygen. These opinions (with the exception of the oxygen in cast-iron) have been acceded to by succeeding chemists. I have stated above what I consider as the composition of cast-iron. And I shall now state the experiments which I made on cast-steel.

I attempted to analyze specimens of cast-steel furnished me for the purpose by Mr. Buttray, an excellent steel-maker in the neighbourhood of Glasgow, and the general result of my trials gave me the constituents as follows :

Iron	. .	99
Carbon with some silicon	. .	1
		———
		100

Now this approaches

20 atoms iron	. . .	70
1 atom carbon		0·75
		———
		70·75

I am therefore disposed to consider this as likely to be the constitution of cast-steel.

I made no attempts to determine the constitution of blistered steel; probably the proportion of carbon in it is rather less. If we could draw any conclusion from the analyses of several kinds of steel published by Vauquelin in 1797, its composition is nearly the same as I found in cast-steel. He obtained (stating the maximum) from 100 parts of the steel

Iron	. .	97·597		Carbon	. .	0·789
Silica	. .	0·315		Phosphorus	.	1·520

Now if we convert the silica into silicon, and add it to the car-

bon, and consider the phosphorus as an accidental ingredient, the carbon will amount to nearly 1 per cent., the same as I obtained from cast-steel.

It is a very desirable thing to combine the extreme hardness of steel with the toughness and tenacity of iron. This is done by welding them together. It is in this way that edge-tools are made. A bit of steel is welded to the iron on that side of the plate or bar which is to be worked into an edge.

Case-hardening.   There is another way which is peculiarly serviceable on particular occasions. The surface of a piece of iron is converted into steel by cementation, and the process is stopped before the carbon penetrate so far as to convert the whole piece into steel. This is called *case-hardening*. The piece of work when nearly finished is covered with a paste made of combustible matters. Certain animal substances, as horns and hoofs, chopped hair, bone shavings, &c. are made up into a paste. The iron is covered with it and the whole wrapt up in clay. This is first dried and hardened before the fire and then put into a forge, and kept in a low red-heat for an hour or two. When taken out the surface is converted into steel. In this way almost all the parts of gun-locks are treated. Besides the superficial hardness that they acquire, it is well known that they have incomparably less friction than while in the state of iron, and they are much less liable to rust.

From the preceding detail, it is obvious that iron and carbon are capable of combining together in a variety of different proportions. When the carbon exceeds, the compound is carburet of iron. When the iron exceeds, the compound is steel or cast-iron in various states, according to the proportion. All these compounds may be considered as *subcarburets of iron*. The most complete detail of experiments on these various compounds which has appeared in this country are those of Mr. Mushet, published in the Philosophical Magazine. This ingenious practical chemist has observed, that the hardness of iron increases with the proportion of charcoal with which it combines, till the carbon amounts to about $\frac{1}{60}$ of the whole mass. The hardness is then a maximum; the metal acquires the colour of silver, loses its granulated appearance, and assumes a crystallized form. If more carbon be added to the compound, the hardness diminishes in proportion to its quantity.[*]

The following table, by the same ingenious chemist, exhibits the proportion of charcoal which disappeared during the con-

[*] Phil. Mag. xiii. 138.

version of iron to the different varieties of subcarburet known in commerce.*

$\frac{1}{120}$	. .	Soft cast-steel
$\frac{1}{100}$	. .	Common cast-steel
$\frac{1}{90}$	. .	The same, but harder
$\frac{1}{50}$	. .	The same, too hard for drawing
$\frac{1}{25}$	. .	White cast-iron
$\frac{1}{20}$	. .	Mottled cast-iron
$\frac{1}{15}$	. .	Black cast-iron.

VIII. From the experiments of Descotils† and Gmelin‡ we learn, that iron is capable of combining with *boron*. The *boruret* was formed by fusing a mixture of iron filings and boracic acid in a covered crucible. It constituted a ductile mass of a silver white colour. But Arfvedson could not succeed in forming this compound.

Boruret.

IX. From the experiments of Berzelius and Stromeyer, it appears that silicon may be combined with iron. It is even probable, from Berzelius' observations, that some kinds of iron may owe their peculiar qualities to the silicon which they contain. *Silicet* of iron is of a silver white colour and ductile. It requires heat before it dissolves in sulphuric acid. When dissolved in acids it leaves a quantity of silica, constituting a porous mass of the size of the silicet dissolved. Nothing is known respecting the proportions of iron and silicon, capable of uniting.

Silicet.

X. Iron combines with phosphorus in various proportions.

Phosphurets.

1. A phosphuret of iron may be formed by fusing in a crucible 16 parts of phosphoric glass, 16 parts of iron, and half a part of charcoal powder. It is magnetic, very brittle, and appears white when broken. When exposed to a strong heat, it melts, and the phosphorus is dissipated.§ It may be formed also by melting together equal parts of phosphoric glass and iron filings. Part of the iron combines with the oxygen of the phosphoric glass, and is vitrified; the rest forms the phosphuret, which sinks to the bottom of the crucible. It may be formed also by dropping small bits of phosphorus into iron filings heated red-hot.‖ The proportions of the ingredients of this phosphuret have not yet been determined; but from some trials which I made I conclude that the phosphuret made by Pelletier's process is a diphosphuret composed of

1. Diphos-
phuret.

* Phil. Mag. xiii. p. 142.   † Recherches Physico-chimiques, i. 306.
‡ Schweigger's Journal, xv. 246.   § Pelletier, Ann. de Chim. i. 105.
‖ Ibid. xiii. 113.

2 atoms iron	. .	7
1 atom phosphorus	. .	2
		9

This at least seems to be the composition of the phosphuret discovered by Bergman, and called by him *siderum.*

' There is a particular kind of iron known by the name of *cold short iron,* because it is brittle when cold, though it be malleable when hot. Bergman* was employed at Upsala in examining the cause of this property, while Meyer† was occupied at Stetin with the same investigation; and both of them discovered, nearly at the same time, that by means of sulphuric acid, a white powder could be separated from this kind of iron, which by the usual process they converted into a metal of a dark steel gray, exceedingly brittle, and not very soluble in acids. Its specific gravity was 6·700; it was not so fusible as copper; and when combined with iron rendered it *cold short.* Both of them concluded that this substance was a *new metal.* Bergman gave it the name of *siderum,* and Meyer of *hydrosiderum.* But Klaproth soon after, recollecting that the salt composed of phosphoric acid and iron bore a great resemblance to the white powder obtained from cold short iron, suspected the presence of phosphorus in this new metal. To decide the point, he combined phosphoric acid and iron, and obtained, by heating it in a crucible along with charcoal powder,‡ a substance exactly resembling the new metal.§ Meyer, when Klaproth communicated to him this discovery, informed him that he had already satisfied himself, by a more accurate examination, that siderum contained phosphoric acid.|| Soon after this, Scheele actually decomposed the white powder obtained from cold short iron, and thereby demonstrated that it is composed of phosphoric acid and iron.¶ The siderum of Bergman, however, is composed of phosphorus and iron, or it is phosphuret of iron; the phosphoric acid being deprived of its oxygen during the *reduction.***

* Opusc. iii. 109.

† Schriften der Berliner Gessellch. Naturf. Freunde, 1780, ii. 334, and iii. 380.

‡ This process in chemistry is called *reduction.*

§ Crell's Annals, 1784, i. 390. || Ibid. 195.

¶ Crell, i. 112, Eng. Trans.

** Rinman has shown that the brittleness and bad qualities of cold short iron may be removed by heating it strongly with lime-stone, and with this the experiments of Levavasseur correspond. See Ann. de Chim. xlii. 831.

2. When a current of dry hydrogen gas is passed over phosphate of iron heated to redness in a glass tube, both the constituents are deprived of their oxygen, and a phosphuret remains, which is obviously a compound of

1 atom iron	. . .	3·5
1 atom phosphorus	. . .	2
		———
		5·5

so that its atomic weight is 5·5.

3. M. H. Rose formed a phosphuret of iron by passing a current of phosphuretted hydrogen gas very slowly over iron pyrites (bisulphuret of iron). The hydrogen gas united to the sulphur, and formed sulphuretted hydrogen, while the phosphorus combined with the iron. Now phosphuretted hydrogen is a compound of

$1\frac{1}{2}$ atoms hydrogen
1 atom phosphorus,

while iron pyrites is a compound of

2 atoms sulphur
1 atom iron.

Sulphuretted hydrogen is a compound of

1 atom hydrogen
1 atom sulphur.

It is obvious that 4 atoms phosphuretted hydrogen contain

6 atoms hydrogen
4 atoms phosphorus,

while 3 atoms iron pyrites contain

6 atoms sulphur
3 atoms iron.

4 atoms of phosphuretted hydrogen and 3 atoms iron pyrites may therefore be converted into 6 atoms sulphuretted hydrogen, and into a phosphuret of iron composed of

4 atoms phosphorus
3 atoms iron.

Now this was the phosphuret obtained by Rose.* He has not given us any account of its properties. I should be disposed to consider it as a mixture of 2 atoms phosphuret of iron and 1 atom of biphosphuret.

XI. There exists a strong affinity between iron and sulphur. No fewer than 5 sulphurets are now known, and doubtless various other combinations of the two constituents will be discovered hereafter.

* Ann. de Chim. et de Phys. xxxiv. 176.

1. Sulphuret of iron may be formed by various processes; one of the surest is to pass dry hydrogen gas over iron pyrites in powder and heated to redness in a glass or porcelain tube. One half of the sulphur is disengaged, and there remains a combination of

1 atom sulphur	.	.	2
1 atom iron	.	.	3·5
			5·5*

The same compound is obtained when iron is heated to whiteness surrounded by sulphur vapour. The union is accompanied by the fusion of the sulphuret, and a good deal of heat is evolved. Its colour is that of bronze or black when in powder, and it dissolves in sulphuric or muriatic acid with the evolution of abundance of sulphuretted hydrogen gas. It may be obtained also when iron pyrites is distilled at a red-heat; one-half of the sulphur flies off, and leaves sulphuret of iron.

The mineral called magnetic pyrites is a combination of 5 atoms sulphuret of iron and 1 atom of bisulphuret, as was first shown by Stromeyer.† Its colour is that of bronze; it has the metallic lustre; but its powder is blackish gray. Its specific gravity is 4·518. It strikes fire with steel, and easily melts when heated. According to the analysis of Stromeyer it is composed of

Iron.	. .	.	100
Sulphur	.	.	67·084.

Now if we suppose it a compound of 5 atoms sulphuret and 1 atom bisulphuret of iron, the weight of its constituents would be

Iron	.	. .	100
Sulphur	.	.	66·66

which almost coincides with Stromeyer's result.

2. *Sesquisulphuret of iron* may be formed by passing a current of dry sulphuretted hydrogen gas over peroxide of iron in a glass or porcelain tube, and heated to the temperature of 212°. The current of gas is to be continued till all evolution of water is at an end. The sesquisulphuret of iron formed has the same form as the peroxide had. It has a gray colour with a slight shade of yellow, and acquires lustre under the burnisher. It is not altered by exposure to the air. When distilled, sulphur is given out, and common sulphuret of iron remains. When treated with acids, sulphuretted hydrogen gas is evolved,

iron is dissolved, and a quantity of bisulphuret of iron remains undissolved.*   Its constituents are

1½ atom sulphur	. .	3
1 atom iron	. .	3·5
		———
		6·5

3. Bisulphuret of iron may be formed by various processes ; but it is found ready formed in great abundance, and is known by the name of iron or cubic pyrites.   It has a yellow colour, and has the metallic lustre.   It is brittle, and sufficiently hard to strike fire with steel.   Its specific gravity is about 4·5.   It usually crystallizes in striated cubes.   When heated it is decomposed.   In the open air the sulphur takes fire : in close vessels filled with charcoal, part of the sulphur is volatilized ; and a black substance remains, retaining the original form of the mineral, but falling to powder on the slightest touch.   Mr. Proust has demonstrated that this black substance is protosulphuret of iron.   Its constitution was first ascertained by Mr. Hatchett, and his analysis has been confirmed by those of Berzelius and Gueniveau and my own.†   It is a compound of

2 atoms sulphur	. .	4
1 atom iron	. .	3·5
		———
		7·5

Some varieties of iron pyrites are not altered by exposure to the air, while others when so exposed split in pieces and are gradually converted into sulphate of iron.   Probably those varieties which are thus decomposed contain some sulphuret of iron mixed with the bisulphuret of iron.

4. Disulphuret of iron was obtained by Arfvedson by passing a current of dry hydrogen gas over anhydrous protosulphate of iron heated in a glass tube.   Sulphurous acid and water came at first over, and at last sulphuretted hydrogen gas.   When the process was concluded there remained a dark gray agglutinated powder, which was strongly attracted by the magnet, and dissolved in muriatic acid with the evolution of sulphuretted hydrogen gas.   It contained no sulphuric acid.   858 parts of anhydrous sulphate of iron were by this treatment converted into 396 of the sulphuret.   Hence the sulphuret was a compound of

* Berzelius ; Poggendorf's Annalen, vii. 393.   † First Principles, i. 354.

Iron   .   .   7·9
Sulphur   .   .   2

7·9 is a little more than two atoms of iron; doubtless because the iron is a little overrated; for it is not possible to deprive sulphate of iron of the water which it contains without driving off sulphuric acid at the same time. There can therefore be no reasonable doubt that the sulphuret formed was a compound of

2 atoms iron   .   .   7
1 atom sulphur   .   .   2
                                 ——
                                 9

It is therefore a disulphuret of iron.*

5. Tetrasulphuret of iron was obtained by Arfvedson by exposing anhydrous dipersulphate of iron to a current of dry hydrogen gas, while heated in a glass tube. Sulphurous acid and sulphuretted hydrogen gas were evolved, and the process continued for a long time. The sulphuret formed resembled metallic iron, reduced from the peroxide by hydrogen gas. It was acted on very powerfully by the magnet, and was semi-malleable; but it dissolved in muriatic acid with the evolution of sulphuretted hydrogen gas. The iron during this process was reduced to the metallic state, and half the sulphur was dissipated. Hence the sulphuret formed was a compound of

4 atoms iron   .   .   14
1 atom sulphur   .   .   2
                                 ——
                                 16

It is therefore a tetrasulphuret of iron.†

Sulphuret of iron is not only attracted by the magnet, but may be itself converted into a magnet by the usual methods; but bisulphuret is not in the least obedient to the magnet, neither is it susceptible of the magnetic virtues.‡

It has been long known that pure iron is not susceptible of retaining the properties of a magnet; but steel, when once magnetized, continues permanently magnetic. Now steel, as we have seen, is a combination of iron and carbon. When the proportion of carbon united to iron is increased to a certain proportion, the iron loses the property of being acted on by the magnet. The addition of a certain portion of sulphur likewise renders iron susceptible of becoming a permanent magnet. The sulphur may amount to 46 per cent. without destroying

* Annals of Philosophy (2d series), vii. 341.   † Ibid. p. 342.
‡ Hatchett, Phil. Trans. 1804.

this property; but when it is increased to 52 per cent. the magnetism vanishes completely. Iron may be made permanently magnetic also when united to phosphorus; but whether the magnetism disappears when the proportion of phosphorus is increased, has not been ascertained.

Thus it appears that pure iron is not susceptable of permanent magnetism. United to a portion of carbon, it forms a compound more or less brittle, soluble in muriatic acid, and susceptible of magnetic impregnation. Saturated with carbon, it becomes brittle, insoluble in muriatic acid, and destitute of magnetic properties.

Iron, united to a portion of sulphur, forms a brittle compound, soluble in muriatic acid, and susceptible of magnetic impregnation. Saturated with sulphur, the compound becomes brittle, insoluble in muriatic acid, and destitute of magnetic properties.

Iron, united to phosphorus, is brittle, and susceptible of magnetic impregnation in a great degree, and in all probability, by saturation, would lose its magnetic properties altogether.

For these facts, which are of the utmost importance, we are indebted to Mr. Hatchett, who was led to the discovery of them by his experiments on magnetic pyrites. " Speaking generally of the carburets, sulphurets, and phosphurets of iron, I have no doubt," says this sagacious philosopher, " but that, by accurate experiments, we shall find that a certain proportion of the ingredients of each constitutes a maximum in the magnetical power of these three bodies. When this maximum has been ascertained, it would be proper to compare the relative magnetical power of steel (which hitherto has alone been employed to form artificial magnets) with that of sulphuret and phosphuret of iron; each being first examined in the form of a single mass or bar of equal weight, and afterwards in the state of compound magnets, formed like the large horseshoe magnets, by the separate arrangement of an equal number of bars of the same substance in a box of brass.

" The effects of the above compound magnets should then be tried against others, composed of bars of the three different substances, various in number, and in the mode of arrangement; and lastly, it would be interesting to make a series of experiments on chemical compounds, formed by uniting different proportions of carbon, sulphur, and phosphorus, with one and the same mass of iron. These quadruple compounds, which, according to the modern chemical nomenclature, may

be called carburo-sulphuro-phosphurets, or phosphuro-sulphuro-carburets, &c. of iron, are as yet unknown as to their chemical properties, and may also, by the investigation of their magnetical properties, afford some curious results. At any rate, an unexplored field of extensive research appears to be opened, which possibly may furnish important additions to the history of magnetism ; a branch of science which of late years has been but little augmented, and which, amidst the present rapid progress of human knowledge, remains immersed in considerable obscurity."

Seleniet. XII. When a mixture of selenium and iron filings is heated, a combination takes place without any appearance of combustion. But if selenium be put into the bottom of a glass tube and iron filings above it, and a sufficient heat be applied to volatilize the selenium, the iron filings absorb this vapour and become red-hot, and this ignition continues as long as any selenium is absorbed. Seleniet of iron thus formed, has a metallic appearance, and a gray colour with a shade of yellow. It does not melt, but becomes agglutinated together into a coherent mass. When heated before the blow-pipe it lets go a portion of selenium, and is converted into a black brittle crystallized matter, which seems to be seleniate of iron. It dissolves readily in muriatic acid, while selenietted hydrogen gas is disengaged. This is the best mode of obtaining this gas. Besides selenietted hydrogen, there is another gas disengaged neither soluble in water nor in caustic alkalies. This gas has a very disagreeable smell, which adheres long to glass vessels. It precipitates protonitrate of mercury black.*

Arseniet. XIII. When 100 parts of iron filings and 200 parts of arsenic are heated to redness, there remain 236 parts of an alloy of iron and arsenic. It is white, very brittle, and easily pulverized.† It is obviously a compound of

1 atom iron	.	.	3·5
1 atom arsenic	.	.	4·75
			8·25

XIV. The alloy of tellurium and iron has not been examined.

Antimoniet. XV. Iron combines with antimony by fusion, and forms a brittle hard white-coloured alloy, the specific gravity of which is less than intermediate. The magnetic quality of iron is much more diminished by being alloyed with antimony than

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* Berzelius, Ann. de Chim. et de Phys. x. 242.   † Gehlen.

with most other metals.* This alloy may be obtained also by fusing in a crucible 2 parts of sulphuret and 1 of iron. It was formerly called *martial regulus.*

XVI. When oxides of iron and chromium are mixed Chromiet. together, and strongly heated in a covered crucible lined with charcoal, they are reduced and melt together into an alloy. And they seem capable of uniting in all proportions. An alloy of these two metals in the proportion of

> 4 atoms chromium,
> 3 atoms iron,

was examined by Berthier. It had been melted and was filled with cavities lined with prismatic crystals. Its texture was crystalline, and its colour whiter than that of platinum. It was hard enough to cut glass as readily as the diamond, and it was so brittle that it was easily reduced to powder in an agate mortar. Berthier formed two alloys of steel and chromium, one containing 1 per cent., the other 1½ per cent. of the later metal. He found both to answer exceedingly well for making cutting instruments, and recommends them accordingly to the attention of manufacturers.†

XVII. Equal quantities of iron and molybdenum melt readily, Molybdet. and form a brittle alloy, of a bluish-gray colour, and considerable hardness. Its fracture was fine scaly, and granular. Before the blow-pipe it melted with intumescence, but without sparks. One part of iron and two of molybdenum formed a brittle alloy of fine grained texture, and light-gray colour. It was magnetic, and did not melt before the blow-pipe. Of all the metals, iron seems to unite most readily with molybdenum.‡

XVIII. Tungsten with white cast-iron gave a perfect button, Tungstet. the fracture of which was compact and of a whitish-brown colour. 100 parts iron and 50 of tungstic acid yielded 137 parts of alloy.§

XIX. When oxide of columbium is mixed with iron filings Columbet. and strongly heated in a small crucible, it is reduced to the metallic state, and forms an alloy with the iron. This alloy has the appearance of white cast-iron, except that it wants its crystalline texture. It is sufficiently hard to scratch glass. Aqua regia dissolves the iron with difficulty, and leaves the columbium in the state of a gray powder.

* Gellert, p. 136. † Ann. des Mines, vi. 579.
‡ Crell's Annals, iii. 370. § Elhuyarts.

XX. It would appear probable from the experiments of Vauquelin and Hecht, that iron and titanium may be united together by heat. At least they obtained a gray coloured mass, interspersed with yellow particles which they were not able to fuse.

XXI. Iron may be alloyed with potassium and sodium. But these alloys cannot be preserved, and of course are of little use at present. Serullas formed an alloy of potassium, iron, and antimony, by heating in a crucible 100 parts of iron filings, over which he put 100 parts of calcined cream of tartar, mixed with 100 parts of powdered antimony. The alloy was brittle, and contained a great deal of potassium.*

XXII. Lampadius exposed to a white heat a mixture of 1 barytes, 1 iron, and ¼ charcoal; he obtained an alloy, which, when exposed to the air, soon fell to powder.†

XXIII. Nothing precise has hitherto been ascertained respecting the alloys of iron with strontium, calcium, and magnesium. Davy obtained alloys of iron with aluminum and glucinum, by exposing to a white heat a mixture of iron and potassium, with alumina or glucina. They were whiter than iron, and underwent decomposition when put into water.

Nothing is known respecting the alloys which iron may be capable of forming with yttrium, cerium, zirconium, or thorium.

SECTION II.—OF MANGANESE.

The dark brown or black mineral called *manganese*, in Latin *magnesia* (according to Boyle from its resemblance to the *magnet*), has been long known and used in the manufacture of glass. A mine of it was discovered in England by Boyle. A few experiments were made upon this mineral by Glauber in 1656,‡ and by Waiz in 1705;§ but chemists in general seem to have paid but very little attention to it. The greater number of mineralogists, though much puzzled what to make of it, agreed in placing it among iron ores; but Pott, who published the first chemical examination of this mineral in 1740, having ascertained that it often contains scarcely any iron, Cronstedt, in his *System of Mineralogy*, which appeared in 1758, assigned it a place of its own, on the supposition that it consisted chiefly of a peculiar earth. Rinman examined it

* Ann. de Mines, viii. 149.
† Schweigger's Journal fur Chemie, xv. 146.
‡ Prosperitas Germaniæ.   § Weigleb's Geschichte, i. 127.

anew in 1765;[*] and in the year 1770 Kaim published at Vienna a set of experiments, in order to prove that a peculiar metal might be extracted from it.[†] The same idea had struck Bergman about the same time, and induced him to request of Scheele, in 1771, to undertake an examination of manganese. Scheele's dissertation on it, which appeared in 1774, was a master-piece of analysis, and contains some of the most important discoveries of modern chemistry. Bergman himself published a dissertation on it the same year; in which he demonstrates, that the mineral, then called *manganese*, is a metallic oxide.[‡] He accordingly made several attempts to reduce it, but without success; the whole mass either assuming the form of scoriæ, or yielding only small separate globules attracted by the magnet. This difficulty of fusion led him to suspect, that the metal he was in quest of bore a strong analogy to platinum. In the mean time, Dr. Gahn, who was making experiments on the same mineral, actually succeeded in reducing it by the following process : He lined a crucible with charcoal powder moistened with water, put into it some of the mineral formed into a ball by means of oil, then filled up the crucible with charcoal powder, luted another crucible over it, and exposed the whole for about an hour to a very intense heat. At the bottom of the crucible was found a metallic button, or rather a number of small metallic globules, equal in weight to one-third of the mineral employed.[§] It is easy to see by what means this reduction was accomplished. The charcoal attracted the oxygen from the oxide, and the metal remained behind. The metal obtained, which is called *manganese*, was farther examined by Ilseman in 1782, Hielm in 1785, and Bindheim in 1789. An elaborate and extensive set of experiments on this metal and its combinations was published by Dr. John in 1807.[||] Since that period many important facts respecting manganese have been ascertained. Arfvedson and Berzelius have determined the composition of its oxides.[¶] And an excellent paper on the same subject has been published by Berthier, characterized by the accuracy and clearness which distinguishes the experiments of this excellent chemist.[**] The investigations of Chevillot and Edwards have

* Mem. Stockholm, 1765, p. 235.
† De Metallis dubiis, p. 48.   ‡ Opusc. ii. 201.   § Bergman, ii. 211.
|| Gehlen's Journal, für die Chemie und Physik, iii. 452.
¶ Annals of Philosophy (2d series), vii. 267.
** Ann. de Chim. et de Phys. xx. 186.

made us acquainted with a new compound of manganese and oxygen possessing acid properties,* and this subject has been much elucidated by the excellent paper published on the same subject by M. Forchhammer.† Much new light has been thrown upon the nature of manganese and its ores by the interesting papers of M. Haidinger and Dr. Turner published in the 11th volume of the Philosophical Transactions of Edinburgh.

Manganese never occurs in nature in the metallic state except when it is combined with sulphur. Twenty different species of manganese ores have been described by mineralogists; by far the most abundant of which is what is usually called *black oxide of manganese.* Under this name various species of manganese ores are included. Sometimes it is pure *binoxide of manganese.* It is then black, has the metallic lustre, and has a fibrous structure. Haidinger has distinguished this species by the name of *pyrolusite.* But most frequently it contains water, binoxide of manganese, and not seldom barytes. It is from this *black oxide,* used extensively in commerce and ground to a fine powder, that chemists obtain pure oxide of manganese, from which this metal is to be procured. And there are various processes which are followed for this purpose.

I am in the habit of obtaining chlorine gas for all the purposes for which it is required by digesting muriatic acid on black oxide of manganese in powder. By this process a solution of manganese in the acid is obtained. It is always contaminated with a good deal of iron; and sometimes it contains copper and likewise barytes. Copper is easily thrown down by passing a current of sulphuretted hydrogen gas through the solution. I then render it as neutral as possible by evaporation, and after diluting it with water I add ammonia in small quantities at a time as long as the precipitate appears red. I then filter. The liquid which passes through is colourless like water. It is proper to try whether the whole iron has been thrown down by putting a few drops of it into a watch-glass and adding a drop of the solution of prussiate of potash. If the precipitate be quite white without any shade of blue, we may be sure that no iron is present. If the black oxide

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* Ann. de Chim. et de Phys. viii. 337.

† Dr. Forchhammer's experiments were the subject of a Thesis published at Copenhagen. An abstract was inserted in the Annals of Philosophy (2d series), i. 50.

was free from barytes nothing more is necessary to have the manganese quite pure. But if barytes be present we must add a solution of sulphate of ammonia as long as a precipitate continues to fall. The liquor being now filtered and mixed with a sufficient quantity of bicarbonate of potash, pure carbonate of manganese falls to the bottom, which requires only to be washed and dried.

Forchhammer's process is in some respects preferable to mine. He mixes equal weights of sulphuric acid and black oxide, and heats the mixture till the vapour of sulphuric acid ceases to appear. By this process the whole is converted into sulphate of manganese, mixed of course with sulphate of iron, &c. This matter is dissolved in water and the solution filtered. This frees the manganese of *barytes* and *lead*, when these bodies happen to be present.* The solution is cautiously mixed with hydrosulphuret of ammonia as long as the precipitate, which falls, is black. This throws down the copper and iron, and leaves the manganese. It is then filtered and heated, and decomposed in the usual way by bicarbonate of potash.†

M. Quesneville, junior, has proposed another process for separating iron and manganese, which I have not tried, as I consider my own to be more economical. He renders the muriatic acid solution of them as neutral as possible by boiling. He then dilutes the liquid with a great quantity of water, and passes a current of chlorine through it to peroxidize the iron. Arseniate of potash being now added throws down the whole iron in the state of a greenish white arseniate. After filtration evaporate the liquid which contains the arseniate of manganese almost to dryness, and add water to it; then filter and decompose the solution by caustic-potash; the oxide of manganese thus obtained is free from iron.‡

M. Lassaigne has given another process, which is nearly allied to the method long ago employed by Dr. John. The black oxide of manganese is digested in dilute muriatic acid to get rid of the carbonate of lime, &c. should it be present. It is then dissolved in sulphuric acid, and the solution evaporated to dryness. Dissolve the dry mass in water, filter, add a little sulphuric acid and pass a current of sulphuretted hydrogen gas through it to precipitate the copper, should any be

* I have never observed lead in the black oxide used in Glasgow for preparing bleaching powder.
† Annals of Philosophy (2d series), i. 50.
‡ Phil. Mag. (2d series), i. 72.

present. Heat the liquid to drive off the excess of sulphuretted hydrogen, and then throw down the manganese by carbonate of soda. Wash the yellow precipitate and digest it in a solution of oxalic acid. The oxide of iron will be dissolved, and the oxalate of manganese will remain in the state of a white powder. When this oxalate after being washed and dried is calcined in a covered crucible, it leaves pure protoxide of manganese.*

If we put pure oxide or carbonate of manganese into a covered crucible lined with charcoal and expose it to a very violent heat for four hours, it will be reduced to the metallic state and fused into a solid mass. In this way metallic manganese was obtained by Mr. Buttray, who exposed the oxide to the greatest heat which can be raised in his furnaces for fusing cast-steel. The manganese which he made was not free from iron; because the oxide which he employed was impure. It was an alloy of nearly 4 atoms manganese and 1 atom iron.

Properties. I. Manganese obtained in the way just described has a gray colour, somewhat whiter than cast-iron. It is fine granular in its texture, hard and so brittle that it may be reduced to powder in a mortar. Its specific gravity, as determined by John, is 8·013.† It is not attracted by the magnet. Even the alloy composed of 4 atoms manganese and 1 atom iron, is not in the least acted on by the magnet, nor does it affect the most delicately poised magnetic needle. Metallic manganese gradually absorbs oxygen from the atmosphere and decomposes water; but when alloyed with iron it loses that property, undergoing no other change by keeping, except becoming a little yellow on the fractured surface.

Oxides. II. Manganese has a strong affinity for oxygen. It is capable of forming, at least, 4 oxides, and there are strong reasons for believing in the existence of a fifth, which contains less oxygen than any of the others. But it is not of much consequence, as it neither possesses the properties of a base nor an acid. It has been distinguished by the name of *suboxide.*

1. Protoxide. 1. The protoxide of manganese constitutes the base of all the salts of manganese. It may be obtained by exposing the carbonate of manganese to a white heat in a covered crucible lined with charcoal; or still more easily by passing a current

* Ann. de Chim. et de Phys. xl. 329.
† Gehlen's Jour. iii. 460.

of dry hydrogen gas over binoxide or sesquoxide of manganese heated in a glass tube, but not to redness. Protoxide thus obtained is a light green powder, which very speedily becomes yellow and at last brown, by absorbing oxygen from the atmosphere. Even in the state of carbonate I have never been able to preserve it for any length of time without a portion of it being converted into deutoxide.

I satisfied myself by a careful analysis of sulphate of manganese, that the atomic weight of protoxide of manganese is 4·5. There can be little doubt from a comparison of it with the other oxides of this metal, that it is a compound of

1 atom manganese,		.	3·5
1 atom oxygen,	.	.	1·
			———
			4·5

consequently the atomic weight of manganese is 3·5, or the same as that of iron.

2. The easiest way of forming the sesquoxide of manganese is to dissolve carbonate of manganese in nitric acid, to evaporate the solution to dryness, and to raise the dry mass by degrees to an incipient red heat. What remains is deutoxide in a state of purity. It is a black powder having considerable lustre, but not in the least metallic. It is tasteless and insoluble in water; but it dissolves by digestion in sulphuric and muriatic acids, and the solutions are red. The muriatic acid solution becomes gradually colourless, but the sulphuric acid solution may be kept unaltered for a considerable length of time. This oxide occurs native in considerable quantity, both anhydrous and in the state of hydrate. The anhydrous has been called braunite by Haidinger; it is a gray black without much lustre, and very hard. When the native *binoxide* of manganese is exposed to a low red-heat it is converted into *sesquoxide*, a quantity of oxygen being driven off. I have shown, by a very simple experiment, that when 4·5 protoxide of manganese is converted into sesquoxide its weight becomes 5.* It is therefore a compound of 4·5 protoxide and 0·5 oxygen, or, which is the same, of

1 atom manganese,	.	.	3·5
1½ atom oxygen,	.	.	1·5
			———
			5

3. When sesquoxide or binoxide of manganese is exposed

* First Principles, i. 368.

to a strong red-heat, it gives out oxygen and assumes a new colour, which varies according to the state of the oxide subjected to heat. If we employ the hydrated binoxide the colour is a rather fine red; but when we employ native binoxide or sesquoxide in a state of strong aggregation the colour is reddish brown or even brownish black. This red oxide occurs native; and it is formed whenever the protoxide of manganese is strongly heated in an open vessel. It is in the state of red oxide that manganese is usually obtained in chemical analyses. Arfvedson has shown that this red oxide is a compound of

1 atom protoxide of manganese,	. . ʊ	4·5
2 atoms sesquoxide of manganese,	. .	10.

14·5*

or we may represent its constitution as follows, which is more convenient in chemical analyses,

Manganese,	. . .	3·5
Oxygen,	. . .	1·333

So that every 4·833 parts of it are equivalent to 4·5 parts of protoxide of manganese.

This red oxide then is not a peculiar oxide of manganese, but a combination of two other oxides. It is precisely the same in its composition with the *oxydum ferroso-ferricum* of Berzelius, and has been called by Arfvedson *oxydum manganeso-manganicum*.

3. Binoxide. 4. The binoxide of manganese exists native, and has been called *pyrolusite* by Mr. Haidinger. Its colour is iron black, its lustre metallic, and its texture fibrous. It is soft, rather sectile, and has a specific gravity varying from 4·94 to 4·819.† It constitutes the most important of all the species of manganese ore from the property which it has of giving out oxygen gas when heated. This oxide may be also formed artificially by various processes. Berthier obtained it by mixing carbonate of manganese with water and passing a current of chlorine gas through the liquid, 'till it exists in considerable excess. Carbonic acid was disengaged, the manganese assumed a brown colour, and was partly dissolved in the state of muriate. What remained undissolved when the quantity of chlorine used was sufficient was a hydrated teroxide. By digesting it in acetic or dilute nitric acid the carbonate is dissolved out, if any should

* Annals of Philosophy (2d series), vii. 267.
† I found the specific gravity of a specimen nearly pure only 4·69.

remain, and the pure hydrated binoxide obtained. It is a very bulky and very light powder; which retains its bulk when dried on the water-bath, and assumes a dark brown colour, and adheres strongly to those bodies with which it comes in contact. From Berthier's analysis it appears to be a compound of

1 atom binoxide,	.	.	5·5
1 atom water,	.	.	1·125
			6·625

But the quantity of water actually obtained was only 0·75 of an atom. For he found the hydrated oxide composed of

Binoxide,	.	.	.	88
Water,	.	.	.	12
			100*

When a neutral solution of protoxide of manganese is mixed with a solution of chloride of soda, made by adding carbonate of soda to a solution of neutral chloride of lime till the lime is all precipitated, a beautiful black precipitate falls, which, when washed and dried, I found a compound of

3 atoms binoxide of manganese,	.	.	16·5
1 atom water,	.	.	.	1·125
			17·628

It is therefore a trishydrated binoxide.† When we precipitate muriate of manganese by neutral chloride of lime, we obtain a very bulky, light, tasteless powder, having a pretty deep reddish brown colour, and which I found by analysis to be a compound of

9 atoms binoxide of manganese,
1 atom lime,
12 atoms water.

The lime cannot be removed by washing, but probably it would by digestion in nitric or acetic acid.

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* Ann. de Chim. et de Phys. xx. 191.

† Was this the same with the hydrated binoxide which Berthier obtained by boiling concentrated nitric acid in the hydrated binoxide, formed by a current of chlorine? He found the new hydrate a compound of

Binoxide,	.	95·5 or 24
Water,	.	.	4·5 or 1·125
		100·0

This is rather more than 4 atoms of manganese to 1 atom of water. It should therefore be a tetrahydrated binoxide.

I found that when 5·5 parts of anhydrous binoxide of manganese are heated to redness they give out 0·5 of oxygen, and are converted into sesquoxide. This experiment was corroborated by Berthier. He heated 18·8 parts of pure native binoxide from Crettnich to whiteness in a charcoal crucible. It was converted into protoxide, and had lost 3·42 parts of its weight which was oxygen.* Thus it appears that binoxide of manganese is a compound of

Protoxide,	.	.	15·38 or 4·5
Oxygen,	. .	.	3·42 or 1·0006

4·5 represents the atomic weight of protoxide of manganese, and 1·0006 comes so near 1 atom of oxygen, that we can have no hesitation in concluding that binoxide is a compound of

1 atom protoxide,	.	.	4·5
1 atom oxygen,	.	.	1.
			———
			5·5

Now as the protoxide contains just one atom of oxygen, it is plain that binoxide of manganese is a compound of

1 atom manganese,	.	.	3·5
2 atoms oxygen,	.	.	2
			———
			5·5

5. Scheele first discovered that when binoxide of manganese is strongly heated with potash or saltpetre, and the mixture dissolved in water, a fine red solution is obtained; which, from the property that it had of changing its colour, by spontaneous decomposition, he called *chameleon mineral.* Cheviller and Edwards showed that from this chameleon mineral a red coloured salt might be obtained, composed of an acid, having manganese for its base and potash. To this acid the name of *manganesic* has been given. When the crystals of this salt are heated in contact with hydrogen gas they set it on fire. They detonate violently with phosphorus, set fire to sulphur, arsenic, and antimony, and indeed to all combustible bodies tried.† A very important set of experiments on manganesic acid was made by Dr. Forchhammer, and published by him in 1820, in his Thesis *de Mangaño.* In the year 1824, an elaborate set of experiments on it, together with an analysis of it, was published

by Professor Frommherz;[*] and in 1826 it was again prepared
and analyzed by Unverdorben.[†]

Various methods of obtaining this acid in a separate state
have been proposed, several of them founded on the method
first practised by Dr. Forchhammer, and which I have described
elsewhere.[‡]   The method employed by Frommherz was this :
He mixed together 2 parts of nitrate of barytes and 1 part of
binoxide of manganese, and exposed the mixture in a crucible
to a strong red-heat.   By this process he obtained a light
green mass, which Forchhammer had shown to be a subman-
ganate of barytes.   This matter was reduced to a very fine
powder, suspended in water and decomposed by a current of
carbonic acid gas disengaged from powdered calcareous spar,
by means of diluted sulphuric acid.   The water amounted to
about 30 times the weight of the submanganate.   It was put
into a glass cylinder, and was very frequently stirred during
the whole operation.   The current of carbonic acid was con-
tinued till the liquid assumed a violet colour, and till the sedi-
ment at the bottom was no longer green but had become brown.
To throw down the carbonate of barytes, which was in solu-
tion, the liquid was boiled for a quarter of an hour.   Only a
very little barytes now remained in solution, which was thrown
down by a drop or two of sulphuric acid.   The liquid now con-
sisted of a solution of manganesic acid in water.   It was concen-
trated by boiling, and then evaporated to dryness in a gentle
heat.

Manganesic acid thus obtained was in very small needles,
which appear from Frommherz's analysis to be a compound of

<div style="text-align:center">

2 atoms manganesic acid,
1 atom water,
</div>

or to be a dihydrated acid.   This water is essential to the exist-
ence of the acid.   When we attempt to drive it off the acid is
decomposed.   The colour of manganesic acid is dark carmine
red.   It has no smell.   It has a disagreeable taste, a kind of
mixture of bitter and astringent.   It is heavier than water.   It
is capable of being converted into vapour by heat, and may
be again condensed without decomposition.   When mixed with
sulphuric acid the temperature rises to at least 266°, and a violet
vapour rises.   When this vapour was condensed by Fromm-
herz he found it a combination of manganesic and sulphuric
acid.   But Unverdorben assures us that he obtained pure man-

* Schweigger's Jahrbuch, xi. 257.   † Poggendorf's Annalen, vii. 322.
‡ First Principles, i. 372.

ganesic acid by distilling a mixture of manganate of potash and sulphuric acid. This vapour has a strong and very peculiar smell.

This acid is not very soluble in water. The specific gravity of a saturated solution, at 68°, is only 1·005. This solution, by transmitted light, has a dark violet colour inclining to carmine. The colouring powers of this acid are very great.

Manganesic acid is gradually decomposed by exposure to light. It is decomposed also by heat. The aqueous solution, if kept at a temperature between 112° and 120°, gradually loses its colour, sesquoxide of manganese being precipitated. The decomposition is still more rapid when the water is kept boiling hot. Oxygen, azote, and chlorine have no action on it whatever. Iodine decomposes it in consequence of its conversion into hydriodic acid. Hydrogen, phosphorus, sulphur, and charcoal, decompose it. Most of the metals have the same effect. It is decomposed by zinc, iron, bismuth, copper, antimony, lead, mercury, and silver in a longer or shorter time. These metals were put into the aqueous solutions in the state of filings. Some decomposed the acid in a few days, others required several weeks.

Sulphuric acid, nitric acid, phosphoric acid, arsenic acid, chromic acid, boracic acid, and carbonic acid, have no action on it. Sulphurous acid and smoking nitric acid destroy it immediately without throwing down any manganese. It is decomposed also by all the hydracids.

Manganesic acid was analyzed by Frommherz by exposing it to heat; it was reduced to sesquoxide, oxygen gas, and water. From 2·14 parts of the acid in needles he obtained

Sesquoxide of manganese . .	1·64
Oxygen	0·32
Water	0·18
	——
	2·14

Now the atomic weight of sesquoxide of manganese is 5, and 164 is to 32 as 5 to 0·98. 0·98 (which differs very little from 1*) is the quantity of oxygen which must unite to sesquoxide of manganese to convert it into manganesic acid. We can have no hesitation in considering manganesic acid as a compound of

* The reason of the deficiency is that Frommherz estimated the specific gravity of his oxygen gas too low. But as he has not given the volume of oxygen gas I cannot apply any correction.

1 atom sesquoxide	.	.	5
1 atom oxygen	.	.	1
			—
			6

Hence its atomic weight is 6. With this view of the composition of the acid the analysis of Unverdorben agrees. But sesquoxide of manganese contains 1·5 atoms of oxygen. Consequently manganesic acid is a compound of

1 atom manganese	.	.	3·5
2½ atoms oxygen	.	.	2·5
			—
			6.

It agrees therefore in its constitution with phosphoric, arsenic, antimonic, and chromic acids.

The binoxide of manganese seems to possess properties approaching much more nearly to those of an acid than an alkali. It is found united in definite proportions to barytes in the manganese ore called by Haidinger Pslomelanite, which is a compound of

3 atoms subsesquihydrate of teroxide,
1 atom quadromanganite* of barytes.

I find also that it combines in definite proportions with lime, and doubtless it may be united also to other bases.

6. There is a native mineral which occurs in Warwickshire, Varvicite. and which Mr. Philips, who first examined it, has distinguished by the name of Varvicite. Dr. Turner observed it also in a specimen of manganese ore from Ihlefeld. It resembles binoxide; but is distinguished by a stronger lustre and a foliated texture. It yields water when heated, and has a specific gravity of 4·531. 100 parts of it being strongly heated, gave out 7·385 grains of oxygen and 5·725 grains of water. There remained 86·89 grains of red oxide of manganese. Hence the constituents are

Manganese	.		62·92	or 3·5
Oxygen	.	.	31·355	or 1·744
Water	.	.	5·725	
			——————	
			100·000†	

Now 1·744 approaches so near 1·75 (which furnishes a definite proportion of oxygen,) that we can have no hesitation in fixing

* By this term manganite I express the combination of binoxide of manganese with a base.

† See Phil. Mag. (2d series), v. 209 ; vi. 281 ; vii. 284.

'upon that number as the true weight of oxygen united to 3·5 manganese. Hence 2 atoms of manganese would be united with 3·5 oxygen. It is obvious from this that varvicite is a compound of

			Mang.	Oxygen.
1 atom sesquoxide	.	.	3·5 +	1·5
1 atom binoxide	.	.	3·5 +	2
			7· +	3·5

It therefore resembles red oxide in its nature; being, however, a compound of two different oxides. The water amounts to half an atom. Thus the compounds of manganese and oxygen at present known amount to six, four of which are direct combinations of manganese and oxygen, the other two compounds of two particular oxides. The following little table exhibits the composition of these oxides

	Mangan.	Oxygen.	Mang.	Oxy.	Atomic weight.
1. Protoxide	1 atom +	1 atom or	3·5 +	1	= 4·5
2. Sesquoxide	1	+ 1½	3·5 +	1·5	= 5
3. Binoxide	1	+ 2	3·5 +	2	= 5·5
4. Manganesic acid	1	+ 2½	3·5 +	2·5	= 6
5. Red oxide	1	+ 1⅓	3·5 +	1·33	= 4·833
6. Varvicite	1	+ 1¾	3·5 +	1·75	= 5·25

The fractions in the last two oxides disappear when we state the composition as follows:

Red oxide is a compound of

1 atom protoxide	.	.	4·5
2 atoms sesquoxide	.	.	10·
			14·5

Varvicite of

1 atom sesquoxide	.	.	5·
1 atom binoxide	.	.	5·5
			10·5

Chlorides.　　III. The oxides of manganese have been examined with great care; but the chlorides have not hitherto attracted much of the attention of chemists. At present we know only two chlorides; namely, the protochloride and perchloride analogous to the protoxide and manganesic acids. The chlorides analogous to sesquoxide and binoxide have not yet been discovered.

Protochloride.　　1. The protochloride was first described by Dr. John Davy.

He obtained it by dissolving the black oxide of manganese in muriatic acid, evaporating the solution to dryness, and exposing the white salt that remains to a red heat in a glass tube with a very narrow orifice. It is a substance of a pure delicate light pink colour and of a lamellar texture, consisting of broad thin plates. It melts at a red heat without alteration in close vessels; but in the open air it is decomposed, muriatic acid being given out and oxide of manganese remaining. When left in an open vessel it deliquesces and is converted into muriate of manganese.

It is obvious from the phenomena of its formation, and from its being converted into neutral muriate of manganese by absorbing water, that it is a compound of

1 atom chlorine	. .	4·5
1 atom manganese	. .	3·5
		8

so that its atomic weight is 8.

2. Perchloride of manganese was discovered by M. Dumas. His method of procuring it is to form the common green chameleon mineral and to change it to red chameleon by means of sulphuric acid. When the solution is evaporated, a mixture of sulphate and manganate of potash is obtained. Mix this matter with concentrated sulphuric acid, and project into it common salt by small fragments at a time, as long as coloured vapours continue to exhale. The perchloride of manganese is given out in the form of a green vapour, which being made to pass through a glass tube surrounded with a mixture of snow and salt, condenses into a greenish-brown liquid. It retains its elastic form at the ordinary temperature of the atmosphere, and is so heavy that it may be poured from one vessel into another. When it comes in contact with water or is mixed with the vapour of water, it is immediately decomposed into muriatic acid and manganesic acid. It is obvious from this that it is a compound of

$2\frac{1}{2}$ atoms chlorine	. . :	11·25
1 atom manganese	. .	3·5
		14·75

so that its atomic weight is 14·75.*

IV. Nothing is known respecting the bromides and iodides of manganese.

V. A curious compound has been discovered by M. Dumas and M. Wöhler, which has every appearance of being a perfluoride of manganese, analogous to manganesic acid. The

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* Ann. de Chim. et de Phys. xxxvi. 81.

method of obtaining it was to mix in a platinum retort 2 parts of chameleon mineral, one part of fluor spar in powder, and a sufficient quantity of concentrated sulphuric acid to convert the whole into a paste. The beak of the retort was plunged into a platinum crucible containing water. A *greenish-yellow gas* comes over, which is rapidly absorbed by the water, and tinges it of a beautiful purple. The solution consists of a mixture of fluoric acid and manganesic acid. Hence it is obvious that the gas must have been a compound of

$2\frac{1}{2}$ atoms fluorine	.	.	5·625
1 atom manganese	.	.	3·5
			9·125

The property which glass has of destroying this gas by combining with the fluorine, has put it out of the power of chemists to examine its properties in detail. When the water containing it is evaporated, oxygen gas is given out and the manganesic acid decomposed.[*]

VI. Nothing is known respecting the compounds which manganese may be capable of forming with hydrogen and azote.

Carburet.

VII. It appears capable of combining with carbon. This compound is formed occasionally in iron-founderies. And in this country it is known by the name of *Keesh*. It occurs occasionally in small cavities in the mass of cast-iron, and seems to be the result of crystallizing during the cooling of the mass. It is composed of thin scales having the lustre and appearance of steel; but very brittle. It was considered as plumbago; and Dr. Wollaston examined it and found that acids have the property of separating from it a little iron. The residuum he found a compound of carbon and manganese. It is therefore a carburet of that metal. Its specific gravity when purified I have found 2·982.

VIII. Nothing is known respecting the compounds of manganese with boron and silicon.

Phosphuret.

IX. Phosphorus may be combined with manganese by melting together equal parts of the metal and of phosphoric glass : or by dropping phosphorus upon red-hot manganese. The phosphuret of manganese is of a white colour, brittle, granulated, disposed to crystallize, not altered by exposure to the air, and more fusible than manganese. When heated the phosphorus burns, and the metal is oxidized.[†]

Sulphuret.

X. We are at present acquainted with only one sulphuret

[*] Ann. de Chim. et de Phys. xxxvi. 82; and xxxvii. 101.
[†] Pelletier, Ann. de Chim. xiii. 137.

of manganese, which may be obtained by various processes. If we mix anhydrous sulphate of manganese with $\frac{1}{16}$th of its weight of charcoal powder, and expose the mixture to an incipient white heat for some time in a covered crucible, it is converted into protosulphuret of manganese.* If we put protoxide of manganese into a glass or porcelain tube and pass a current of sulphuretted hydrogen gas over it while heated to redness till all formation of water is at an end, we obtain pure sulphuretted manganese.† Sulphuret of manganese exists native, having been found at Nagyag in Transylvania, and in Cornwall. It is a black opaque substance with a dark green streak. When formed artificially it is green. Its specific gravity is about 4; and it is said to occur crystallized in cubes. When dissolved in acids it gives out sulphuretted hydrogen in abundance, and is converted into a salt of protoxide of manganese. It is evident from this that it is a compound of

1 atom manganese,	.	.	3·5
1 atom sulphur,	.	.	2
			——
			5·5

so that its atomic weight is 5·5.

The native sulphuret is a compound of 17 atoms manganese and 18 atoms sulphur. It is probable from this that a bisulphuret of manganese also exists, and that the native sulphuret consists of

16 atoms sulphuret,
1 atom bisulphuret.

2. When a current of hydrogen gas is passed through anhydrous sulphate of manganese, heated to redness in a glass tube, one half of the sulphur is carried off, and one half of the manganese is reduced to the metallic state. Hence it is obvious that the light green powder thus formed is a compound or mixture of

1 atom sulphuret of manganese	.	.	5·5
1 atom protoxide of manganese	..	.	4·5
			——
			10·‡

When carbonate of manganese is heated with sulphur, the manganese is converted chiefly into sulphuret, but there is always formed, at the same time, a little sulphate of manganese which renders the sulphuret impure.§

* Berthier, Ann. de Chim. et de Phys. xxiv. 273.
† Arfvedson, Annals of Philosophy, vii. 332.
‡ Ibid. vii. 329.   § Ibid. p. 333.

XI. Nothing is known respecting the combinations of manganese with selenium, tellurium, arsenic, antimony, and chromium.

Equal parts of manganese and molybdenum melted into an irregular button, not fusible before the blow-pipe, and not colouring borax till after 'it had been roasted.*

Manganese with tungsten gave a button of a dark-bluish brown colour and earthy aspect; and, on examining the internal part of it with a lens, it resembled impure dross of iron: it weighed 107 grains.†

Nothing is known respecting its compounds with potassium, sodium, lithium, borium, strontium, calcium, or magnesium.

It combines readily with iron; indeed it has scarcely ever been found quite free from some mixture of that metal. Manganese gives iron a white colour, and renders it brittle.

From Berzelius' experiments we learn, that manganese enters as a constituent into cast-iron.

SECTION III.—OF NICKEL.

History.

There is found in different parts of Germany a heavy mineral of a reddish brown colour, not unlike copper. When exposed to the air, it gradually loses its lustre, becomes at first brownish, and is at last covered with green spots. It was at first taken for an ore of copper; but as none of that metal can be extracted from it, the miners gave it the name of *Kupfernickel*, or "false copper." Hierne, who may be considered as the father of the Swedish chemists, is the first person who mentions this mineral. He gives a description of it in a book published by him in 1694, on the art of detecting metals. It was generally considered by mineralogists as an ore of copper, till it was examined by the celebrated Cronstedt. He concluded from his experiments, which were published in the Stockholm Transactions for 1751 and 1754, that it contained a new metal, to which he gave the name of *nickel.*

This opinion was embraced by all the Swedes, and indeed by the greater number of chemical philosophers. Some, however, particularly Sage and Monnet, affirmed that it contained no new metal, but merely a compound of various known metals, which could be separated from each other by the usual processes. These assertions induced Bergman to undertake a very labori-

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* Crell's Annals, p. 376.
† Chemical Analyses of Wolfram, translated by Cullen, p. 58.

ous course of experiments, in order, if possible, to obtain *nickel* in a state of purity; for Cronstedt had not been able to separate a quantity of arsenic, cobalt, and iron, which adhered to it with much obstinacy. These experiments, which were published in 1775,* fully confirmed the conclusions of Cronstedt. Bergman has shown that nickel possesses peculiar properties; and that it can neither be reduced to any other metal, nor formed artificially by any combination of metals. It must therefore be considered as a peculiar metal. It may possibly be a compound, and so may likewise many other metals; but we must admit every thing to be a peculiar body which has peculiar properties, and we must admit every body to be simple till some proof be actually produced that it is a compound; otherwise we forsake the road of science, and get into the regions of fancy and romance.

Nickel is rather a scarce mineral, and it occurs always in combination with several other metals, from which it is exceedingly difficult to separate it. These metals disguise its properties, and account in some measure for the hesitation with which it was admitted as a peculiar metal. Since the great improvements that have been introduced into the art of analyzing minerals, chemists of eminence have bestowed much pains upon this metal, and a variety of processes have been published for procuring it in a state of purity. For the brittle metal that is sold under the name of speiss contains abundance of iron and arsenic, and some cobalt, copper, and bismuth. The first set of experiments, after those of Bergman, made expressly to purify nickel, are those of the School of Mines of Paris, of which Fourcroy published an abstract.† Their method was tedious and incomplete. Since the publication of these experiments, no fewer than twelve other processes have been proposed by chemists, all of them ingenious, and attended each with peculiar advantages and inconveniences.‡

In the year 1804 an elaborate paper on nickel was published by Richter,§ and in the year 1811 an excellent set of experiments on this metal and its combinations was published by

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* Bergman, ii. 231.   † Discours Preliminaire, p. 117.
‡ Mr. Philips published a process in Phil. Mag. xvi. 312; Proust another in Jour. de Phys. lvii. 169; Thenard another, in Ann. de Chim. l. 117; Bucholz another, in Gehlen's Jour. ii. 282, and iii. 201; Richter a fifth, Ibid. iii. 244; and Proust a sixth, Ann. de Chim. lx. 275. Since that time we have new processes by Laugier, Berthier, Mill, and Wöhler.
§ Gehlen's Journal, iii. 244.

Tupputi.* About the same time an elaborate analysis of its oxides was made by Rothoff.†

Tupputi's mode of obtaining pure nickel is as follows: The impure metallic substance to be met with in commerce called *Speiss*, is to be reduced to powder and digested in 2½ times its weight of nitric acid diluted with an equal weight of water. When the action is at an end, filter the solution in order to get rid of a quantity of arsenious acid which exists in it in the state of a powder. Evaporate the liquid to ⅟₄th of its bulk; more crystals of arsenious acid will fall; let them be separated by a filter. Then into the liquid, still hot, drop by degrees a solution of carbonate of soda till the precipitate which falls begins to assume a green colour.‡ Then filter the liquid, dilute it with a good deal of water, and add an excess of acid, and pass through it a current of sulphuretted hydrogen gas in order to precipitate the whole of the arsenic. It falls in the state of yellow flocks. When it has been all thrown down, filter again and add a sufficient quantity of potash to precipitate the oxide of nickel which now remains combined with nitric acid. Mix this oxide with 3 per cent. of resin, make it into a paste with oil, and expose it to the most violent heat of a forge in a charcoal crucible. A metallic button of pure nickel will be obtained.

Berthier has paid great attention to the preparation of nickel, and has made us acquainted with various processes by which it can be effected. But the one which he considers as the best and cheapest is the following: Speiss, which is chiefly arseniet of nickel, mixed with three or four other metals, is the substance from which nickel is to be obtained. Reduce the speiss to powder, and mix it with twice its weight of litharge, and fuse it rapidly in a wind furnace. On cooling we obtain a mass of lead, a new speiss, and scoriæ. The new speiss is very nearly freed from all the foreign metals. And by repeating the process we convert it into pure arseniet of nickel. The same purification is accomplished by fusing the speiss repeatedly with half its weight of saltpetre. By these processes the speiss loses rather less than half its weight. The arseniet is now roasted to drive off as much of the arsenic as possible. The roasted ore is mixed with the tenth of its weight of metallic iron, and digested in nitric acid to which a little muriatic acid is added from time

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* Ann. de Chim. lxxviii. 133.   † Berzelius's Lärbok i kemien, ii. 311.
‡ There first falls arseniate of iron in yellowish-white flocks, then arseniate of cobalt in rose-red flocks, mixed with arseniate of copper and some arseniate of manganese.

to time. Evaporate the solution almost to dryness to get rid of the excess of acid, and add a considerable quantity of water. The greatest part of the arseniate of iron remains in flocks. The small quantity contained in solution is thrown down by adding carbonate of ammonia to the solution, drop by drop, taking care to avoid all excess. A current of sulphuretted hydrogen gas is now passed through the liquid, to throw down any copper or lead that might be accidentally present. The filtered liquid is now evaporated to dryness, and the residue exposed to a white heat. It is pure protoxide of nickel.[*]

Wöhler has proposed the following method of purifying nickel. He mixes powdered speiss with three times its weight of carbonate of potash, and as much sulphur, and fuses the mixture in a covered Hessian crucible. The matter is allowed to cool and then digested in water, which dissolves liver of sulphur, and leaves a brass yellow powder which is sulphuret of nickel. This powder is well washed with water, and is now quite free from arsenic.[†]

The sulphuret of nickel thus obtained may be dissolved in a mixture of nitric and sulphuric acid, and a stream of sulphuretted hydrogen gas may be passed through the liquid, to throw down any copper that may happen to be present. We may then throw down the protoxide of nickel by means of an alkaline carbonate, and reduce it to the metallic state by exposure to a high temperature in a charcoal crucible.

The process which I have been accustomed to follow is rather easier than any of the preceding, and, I believe, equally efficacious. It is as follows : Reduce speiss to a coarse powder, and digest it in dilute sulphuric acid to which enough of nitric acid has been added to occasion a brisk effervescence. Concentrate the solution and set it aside. Fine green coloured crystals of sulphate of nickel are deposited. Dissolve these crystals in water, and pass a stream of sulphuretted hydrogen gas through the solution, in order to throw down a little copper which is usually present. Then crystallize a second time. Redissolve in water, and throw down the oxide of nickel by an alkali or alkaline carbonate.

By this process of mine nickel is freed from every impurity, except a little cobalt which speiss usually contains, and which none of the preceding steps has eliminated. Two methods of separating this cobalt have been suggested, both of which are

* Ann. de Chim. et de Phys. xxxiii. 49.
† Poggendorf's Annalen, vi. 227.

easy. The first method is this : Convert the oxide of nickel, supposed to contain cobalt, into oxalate, and dissolve the oxalate in dilute ammonia. Leave the solution exposed to the air; the nickel is deposited in the state of ammonio-oxalate, while the cobalt remains in solution giving it a red colour. The reason is that both of these ammonio-oxalates are soluble in ammonia, but only the ammonio-oxalate of cobalt is soluble in water.* The other method is to mix the oxide of nickel containing cobalt with water, and to pass a current of chlorine gas through it for some time. The cobalt is converted into peroxide which remains undissolved in the state of a black powder, but the oxide of nickel dissolves and forms a solution of muriate of nickel. This process was suggested by Berthier. A good deal of the nickel remains also undissolved in the state of peroxide.

Dobereiner assures us that if oxalate of nickel be put into a glass tube, and exposed to the heat of a spirit lamp, till every thing volatile has been driven off, the ash gray powder that remains is pure metallic nickel. Oxalate of cobalt may be reduced in the same way.†

Properties.   I. Nickel, when pure, is of a fine white colour resembling silver ; and, like that metal, it leaves a white trace when rubbed upon the polished surface of a hard stone.‡ It is rather softer than iron. Its specific gravity, according to Richter, after being melted, is 8·279; but when hammered, it becomes 8·666.§ But Tourte found the specific gravity of Richter's nickel 8·402, and when strongly hammered it was as high as 8·932.‖ According to Tuputi, when fused it is 8·380, and after being hammered it is as high as 8·820.¶ I obtained it from the sulphate of the specific gravity 8·03; but it contained carbon. It is malleable both cold and hot; and may without difficulty be hammered out into plates not exceeding the $\frac{1}{100}$ part of an inch in thickness.** It is attracted by the magnet. Like steel it may be converted into a magnet; and in that state points to the north when freely suspended precisely as a common mag-

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* Laugier; Ann. de Chim. et de Phys. ix. 267.
† Schweigger's Journal, xxvi. 384.
‡ Fourcroy, Discours Preliminaire, p. 117.
§ Gehlen's Journal, iii. 252.
‖ Gehlen's Journal fur die Chemie, Physick und Mineralogie, vii. 444. From Lampadius' experiments it appears that this nickel contained cobalt and arsenic. Tromsdorf's Journal, xvi. 49, as quoted by Tuputi.
¶ Ann. de Chim. lxxviii. 140.
** Richter, Gehlen's Jour. iii. 252.

netic needle.   Acco rding to Lampadius, its magnetic energy
is to that of iron as 35 to 55.† It requires for fusion a very
high temperature.‡ It has not hitherto been crystallized.   It
is not altered by exposure to the air, nor by keeping it under
water.§   From the experiments of Tuputi, it appears that
preparations of nickel possess poisonous qualities.‖

II. Nickel, when moderately heated, is soon tarnished; and
from the observations of Tourte, it appears that it runs through
nearly the same changes of colour that steel does when tem-
pered.   It becomes first light-yellow, then deep-yellow, light
violet-blue, and last of all grayish-blue.¶   It is capable of
combining with two proportions of oxygen, and of forming two
oxides. The protoxide is *blackish ash gray*, the peroxide *black*.

1. By exposure to heat, however long continued, Tuputi was
not able to oxidize this metal completely.   The protoxide is
easily procured by dissolving nickel in nitric acid, and throw-
ing it down by potash, and after washing the precipitate, dry-
ing it and heating it to redness.   The colour of this oxide is
ash-gray, it is not magnetic and dissolves very readily in acids,
but is insoluble in caustic fixed alkalies.   Caustic ammonia
dissolves it, and the solution has a fine sky-blue colour, and is
precipitated by caustic potash, soda, barytes, strontian, or lime.
When we attempt to separate this oxide from bodies insoluble
in ammonia by means of that alkali, we find that a portion of
it always remains attached to the insoluble base, which pre-
vents us from succeeding in our object.   I have shown by a
careful analysis of sulphate of nickel that the atomic weight of
this oxide is 4·25.**   If we consider it as a compound of

$$
\begin{array}{llr}
1 \text{ atom nickel} & . \quad . & 3 \text{·} 25 \\
1 \text{ atom oxygen} & . \quad . & 1 \\
\hline
& & 4 \text{·} 25
\end{array}
$$

* Bergman, Klaproth, Fourcroy, Richter, &c.—Mr. Chenevix had an-
nounced a method of procuring nickel which was not magnetic; but he
afterwards ascertained, that it owed this peculiarity to the presence of
arsenic.

† Annals of Philosophy, v. 62.

‡ According to Richter, its melting point is as high as that of manganese.
Tuputi thinks it rather lower.   I have reduced oxide of nickel in a heat
which had no effect on carbonate of manganese.

§ Richter, Ibid.

‖ Ann. de Chim. lxxx. 188.

¶ Gehlen's Journal, für die Chemie, Physik, &c. vii. 443.

** First Principles, i. 358.

the atomic weight of nickel will be 3·25. The experiments of Rothoff lead to the conclusion that the atomic weight of nickel is 3·71. Berzelius states it at 3·69675; but from what data he does not inform us. Lassaigne makes it 5;[*] but this estimate is undoubtedly above the truth. Bucholz was of opinion that there exists a suboxide which is obtained by decomposing sublimed chloride of nickel by caustic potash. It is yellow, and is neither soluble in caustic ammonia nor in the carbonate of that alkali. I consider the existence of this suboxide as doubtful.

Sesquoxide.   2. The peroxide of nickel was first examined by Thenard. It may be formed by causing a current of chlorine gas to pass through water holding protoxide of nickel suspended in it; a portion is dissolved, and the rest acquires a black colour. This oxide is soluble in ammonia as well as the last; but the solution is accompanied with effervescence, owing to the decomposition of a part of the ammonia by the combination of its hydrogen with part of the oxygen of the oxide. A similar effervescence accompanies its solution in acids, occasioned by the separation of a portion of its oxygen in the state of gas.[†] From the experiments of Rothoff, it appears that this oxide contains 1½ times as much oxygen as the protoxide. Hence it is a compound of

1 atom nickel	. .	3·25
1½ atom oxygen	. .	1·5
		4·75

so that its atomic weight is 4·75.

When the protohydrate of nickel is treated with deutoxide of hydrogen a dark green matter is formed, which has not been examined, but which Thenard considers as containing more oxygen than the black oxide.

Chloride.   III. Nickel does not burn when introduced into chlorine gas. Its oxide is not altered though heated to redness in that gas.[‡] But the chloride of nickel may be formed by leaving nickel in contact with chlorine gas, or by subliming dry muriate of nickel. It is an olive-coloured substance, the properties of which have not been examined.

Iodide.   IV. The bromides and iodides of nickel have not been particularly examined. According to Lassaigne when nickel and iodine are heated in a glass tube a brown fusible mass is obtained, composed of 23·81 nickel and 76·19 iodine. This corresponds with

* Schweigger's Jahrbuch, ix. 108.   † Thenard; Ann. de Chim. 1. 125.
‡ Davy; Phil. Trans. 1811, p. 25.

1 atom iodine	.	.	15·75
1¼ atom nickel	.	.	3·875

$$19·625$$

Nor is any thing known respecting the compounds which it may be capable of forming with hydrogen and azote.

V. It combines with carbon and forms a carburet. Indeed, Carburet. as usually prepared it is never destitute of carbon. Mr. Mill has given the following process for preparing carburet of nickel: Let native arseniet of nickel be finely pounded and mixed with charcoal also pounded, and exposed to a dull red heat for two hours in a flat bottomed crucible. Blow off the charcoal with a pair of bellows and dissolve the nickel in nitro-sulphuric acid, evaporate and crystallize. Pick out the finest crystals, and mix them with a small portion of borax and charcoal powder, and fuse them in a crucible for a quarter of an hour in a strong red heat. Break the crucible, and a button will be found having a strong metallic lustre, very fusible and magnetic.* This button Mr. Mill considers as a carburet, but it undoubtedly contains sulphur. In fact it ought to be a sulphuret composed of

1 atom nickel	.	.	3·25
1 atom sulphur	.	.	2

$$5·25$$

The plumbago looking substance formed by Mr. Ross in his attempt to obtain nickel, may have been a carburet of nickel; but unfortunately it has not undergone a chemical examination.† Mr. Irving‡ it seems had obtained the same substance several years before. In my trials, probably because my furnace produced a higher temperature, I always obtained a button of nickel perfectly fused; but containing some carbon.

VI. Phosphuret of nickel may be formed either by fusing Phosphuret. nickel along with phosphoric glass, or by dropping phosphorus into it while red-hot. It is of a white colour; and, when broken, it exhibits the appearance of very slender prisms collected together. When heated, the phosphorus burns, and the metal is oxidated. It is composed of 83 parts of nickel and 17 of phosphorus.§ This is exactly 3 atoms nickel and 1 atom phosphorus. The nickel, however, on which this experiment was made, was not pure.

According to Lampadius it is composed of 100 nickel + 15

* Annals of Philosophy (2d series), iii. 201.   † Ibid. ii. 62.
‡ Ibid. p. 149.   § Pelletier, Ann. de Chim. xiii. 135.

phosphorus, or 4 atoms nickel $+$ 1 atom phosphorus. It is tin-white, according to him, and has the metallic lustre. It is moderately hard and very brittle. Its fracture is foliated, and it is not attracted by the magnet.*

Sulphurets. VII. Two compounds of sulphur and nickel have been formed by chemists, namely, *sulphuret* and *disulphuret*.

1. Sulphuret. 1. Sulphuret of nickel exists native, and is known to mineralogists by the name of *haarkies*. It occurs at Johangeorgenstadt and Joachimsthal in delicate capillary crystals, of a brass yellow colour. It is brittle, and before the blowpipe easily melts. It dissolves in nitromuriatic acid without any other residue than a little sulphur. Arfvedson analyzed it and found its constituents

Nickel	.	.	.	64·35
Sulphur	.	.	. .	34·26

$$98\cdot61\dagger$$

This is obviously proportional to

1 atom nickel	.	.	3·25
1 atom sulphur	.	.	2

$$5\cdot25$$

if we suppose the loss to have been sulphur, which it probably was.

The same sulphuret may be formed by passing a current of dry sulphuretted hydrogen gas over oxide of nickel, heated to redness in a glass tube. When thus formed it has a dark gray colour; and is not in the least attracted by the magnet.‡

2. Disulphurets. 2. When a current of dry hydrogen gas is passed over anhydrous sulphate of nickel heated in a glass tube to incipient redness, one-half of the sulphur passes off partly in the state of sulphurous acid, and partly in that of sulphuretted hydrogen gas. The sulphuret formed has a pale yellow colour, and when burnished assumes the metallic lustre. It is brittle, and is attracted rather strongly by the magnet. When dissolved in nitric acid it leaves a residue of sulphur.§ It is obvious from Arfvedson's analysis that this substance is a disulphuret of nickel or a compound of

2 atoms nickel	.	.	6·5
1 atom sulphur	.	.	2

$$8\cdot5$$

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* Annals of Philosophy, iv. 63.　　　† Ibid. (2d series), vii. 340.
‡ Arfvedson, ibid. p. 339.　　　§ Ibid. p. 338.

VIII. Nothing is known respecting the combinations which nickel may be capable of forming with selenium and tellurium.

IX. With arsenic nickel combines in two proportions forming an *arseniet* and *diarseniet.*

1. Arseniet of nickel occurs native, and is the mineral known by the name of *coppernickel.* It has a copper red colour, is brittle, has a specific gravity of 7·29, is not magnetic, and melts at a red heat. What is called speiss seems to be nothing else than impure coppernickel which has been fused. This compound, when pure, consists of

$$
\begin{array}{lcc}
\text{1 atom nickel} & . \quad . & 3{\cdot}25 \\
\text{1 atom arsenic} & . \quad . & 4{\cdot}75 \\
\hline
& & 8 \\
\end{array}
$$

so that its atomic weight is 8. This arseniet is easily made artificially by heating nickel and arsenic together. Arsenic has the curious property of depriving all magnetic metals of their property of becoming magnetic.

2. When arseniate of nickel is heated in a crucible lined with charcoal it is converted into a *diarseniet,* which has a grayish-white colour without any shade of red, is brittle, and has a granular texture. Like the other arseniet it is not in the least magnetic.*

X. When one part of nickel in powder and 2 parts of antimony are heated together to redness, they form a dark gray metallic powder.†

XI. Equal quantities of molybdenum and nickel melted into a button, internally of a light-gray colour, yielding somewhat to the hammer before it broke, and exhibiting a granular texture. It was not magnetic, and did not melt before the blow-pipe. When the proportion of molybdenum is increased, the fusion of the alloy becomes more difficult; in other respects, its properties continue nearly the same.‡

XII. We are ignorant of the alloys which nickel is capable of forming with the metallic bases of the fixed alkalies, alkaline earths and earths proper. It combines readily with iron; but the properties of the alloy have not been examined. According to Lampadius an alloy of 5 parts nickel and 2 parts iron is moderately hard, quite malleable, and has the colour of steel.§

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* Berthier; Ann. de Chim. et de Phys. xiii. 60.   † Gehlen.
‡ Crell's Annals, p. 367.   § Annals of Philosophy, v. 62.

SECTION IV.—OF COBALT.

A mineral called *cobalt*,* of a gray colour, and very heavy, has been used in different parts of Europe, since the 15th century, to tinge glass of a blue colour. But the nature of this mineral was altogether unknown till it was examined by Brandt in 1733, This celebrated Swedish chemist obtained from it a new metal, to which he gave the name of *cobalt*.† Lehmann published a very full account of every thing relating to this metal in 1761.‡ Bergman confirmed and extended the discovery of Brandt in different dissertations published in the year 1780.§ Scarcely any farther addition was made to our knowledge of this metal till 1798, when a paper on it was published by Mr. Tassaert.‖ In the year 1800, a new set of experiments were made upon it by the School of Mines at Paris, in order to procure it perfectly pure, and to ascertain its properties when in that state.¶ In 1802, a new series of trials was published by Thenard, which throw considerable light on its combinations with oxygen.** And in 1806, Mr. Proust published a set of expe-

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* The word *cobalt* seems to be derived from *cobalus*, which was the name of a spirit that, according to the superstitious notions of the times, haunted mines, destroyed the labours of the miners, and often gave them a great deal of unnecessary trouble. The miners probably gave this name to the mineral out of joke, because it thwarted them as much as the supposed spirit, by exciting false hopes, and rendering their labour often fruitless; for as it was not known at first to what use the mineral could be applied, it was thrown aside as useless. It was once customary in Germany to introduce into the church-service a prayer that God would preserve miners and their works from *kobalts* and *spirits*. See Beckman's History of Inventions, ii. 362.

Mathesius, in his tenth sermon, where he speaks of *cadmia fossilis* (probably cobalt ore), says, "Ye miners call it *cobalt*; the Germans call the black devil and the old devil's whores and hags, old and black *kobel*, which by their witchcraft do injury to people and to their cattle."

Lehmann, Paw, Delaval, and several other philosophers, have supposed that *smalt* (oxide of cobalt melted with glass and pounded) was known to the ancients, and used to tinge the beautiful blue glass still visible in some of their works; but we learn from Gmelin, who analyzed some of these pieces of glass, that they owe their *blue* colour, not to the presence of *cobalt*, but of *iron*.

According to Lehmann, cobalt ore was first used to tinge glass blue by Christopher Schurer, a glassmaker at Platten, about the year 1540.

† Acta Upsal. 1733 and 1742.
‡ Cadmialogia, oder Geschichte des Farben-Kobolds.
§ Opusc. ii. 444, 501, and iv. 371.   ‖ Ann. de Chim. xxviii. 101.
¶ Fourcroy. Discours Preliminaire, p. 114.
** Ann. de Chim. xlii. 210.

riments upon the same subject.* Considerable attention has been lately paid to the purification of this metal; but hitherto no one seems to have been fortunate enough to hit upon a method altogether free from objections.†

As cobalt in the metallic state has not been applied to any useful purpose, chemists to procure it are obliged to extract it from its ore. The most abundant of these ores is *cobalt glance*, which occurs at Tunaberg in Sweden, and in which the cobalt is united with sulphur and arsenic. Many processes have been contrived to extract pure cobalt from this ore. The following is perhaps one of the easiest.

Reduce the ore to powder, and roast it in a moderate heat to get rid of a portion of the sulphur and arsenic which it contains. Then dissolve it in nitric acid and evaporate the solution to dryness, and digest the dry mass in water. A quantity of arseniate of iron remains undissolved. If the ore contains no iron it would be an improvement to add a little of it before dissolving the ore in nitric acid. Filter off the aqueous solution, and pour into the liquid a quantity of binoxalate of potash dissolved in water. In a few hours the whole cobalt precipitates in the state of oxalate. Digest this oxalate in ammonia, which will dissolve it and set the solution aside in an open vessel till the excess of ammonia has had time to be dissipated. The oxalate of nickel, if any was present, will precipitate, and the oxalate of cobalt, in a state of purity, will remain in solution. Evaporate to dryness, and expose the oxalate of cobalt thus obtained to a red heat in a covered vessel. The cobalt is reduced to the metallic state, and when exposed to a violent heat in a crucible covered with a little borax, it may be fused into a mass of cobalt.‡

I. Cobalt is of a gray colour with a shade of red, and by no means brilliant. Its texture varies according to the heat employed in fusing it. Sometimes it is composed of plates, sometimes of grains, and sometimes of small fibres adhering to each other.§ It has scarcely any taste or smell.

It is rather soft. Its specific gravity, according to Tassaert, is 8·5384.‖ According to Lampadius it is 8·7.¶ It is brittle,

* Ann. de Chim. lx. 260.

† See Richter, Gehlen's Jour. ii. 53; Bucholz, Ibid. iii. 201; Philips, Phil. Mag. xvi. 312.

‡ This process is nearly that of Quesneville, junr. See Ann. de Chim. et de Phys. xlii. 111.

§ L'Ecole des Mines.   ‖ Ann. de Chim. xxviii. 99.

¶ As quoted by Berzelius; Lärbok i Kemien, ii. 295. Bergman and the

and easily reduced to powder; but if we believe Leonhardi, it is somewhat malleable when red-hot. Its tenacity is unknown. When heated to the temperature of 130° Wedgewood, it melts;* but no heat which we can produce is sufficient to cause it to evaporate. When cooled slowly in a crucible, if the vessel be inclined the moment the surface of the metal congeals, it may be obtained crystallized in irregular prisms.†

Like iron, it is attracted by the magnet; and, from the experiments of Wenzel, it appears that it may be converted into a magnet precisely similar in its properties to the common magnetic needle.

It dissolves very slowly in diluted sulphuric and muriatic acids with the evolution of hydrogen gas: but nitric acid dissolves it readily with the evolution of deutoxide of azote.

Oxides. 　II. When exposed to the air it undergoes no change, neither is it altered when kept under water. Its affinity for oxygen is not sufficiently strong to occasion a decomposition of the water. When kept red hot in an open vessel, it gradually imbibes oxygen, and is converted into a powder, at first blue, but which gradually becomes deeper and deeper, till at last it becomes black, or rather of so deep a blue that it appears to the eye black. If the heat be very violent, the cobalt takes fire and burns with a red flame.

Two different oxides of cobalt have been examined and described by chemists, and from the late observations of M. L. Gmelin, there is reason to suspect that there exists a third oxide which possesses acid properties.

1. Protoxide. 　1. The protoxide of cobalt may be obtained by dissolving cobalt in nitric acid, and precipitating the cobalt from the solution by means of potash. The precipitate has a blue colour, but when dried in the open air it gradually becomes greenish. This powder is to be kept for half an hour in that degree of heat known to manufacturers of iron utensils by the name of *cherry-red*. This heat expels the oxygen which it had absorbed in drying, and converts it into a fine blue colour. This oxide dissolves in acids without effervescence. The solution of it in muriatic acid, if concentrated, is green; but if diluted with water, it is red. Its solution in sulphuric and nitric acids is

French chemists, and Hatchett, state the specific gravity as 7·7; but their specimens were obviously impure.

* I have some doubts about the accuracy of this statement. Cobalt does not melt in a temperature at which nickel may be fused into a button.

† Fourcroy, v. 137.

always of a red colour.* It gives a beautiful blue colour to glass, and is used for painting blue or stone-ware. It is soluble in caustic and carbonated ammonia, and the solution has a red colour, and is not precipitated by caustic potash. It dissolves in caustic potash, and the solution has a blue colour. It is thrown down unaltered by dilution with water, and in the state of deutoxide when the solution is exposed to the air.

I have shown, by an analysis of the neutral sulphate of cobalt, that the atomic weight of this oxide is 4·25, or precisely the same as that of protoxide of nickel.† As it is obviously a compound of

1 atom cobalt	3·25
1 atom oxygen	1
	———
	4·25

the atomic weight of cobalt must be 3·25, or the same with that of nickel.

According to Rothoff, this oxide is a compound of

Cobalt	100
Oxygen	27·097

This would make the atom of cobalt 3·691. Berzelius has fixed it at 3·68991; but without assigning any reason for deviating from the estimate of Rothoff, which he professes to follow.

2. Sesquox ide.

2. When the protoxide of cobalt, newly precipitated from an acid, is dried by heating it in the open air, it assumes a flea-brown colour, which gradually deepens till at last it become black. This is the peroxide of cobalt. It may be formed also by passing a current of chlorine gas through water, in which the protoxide is suspended, or by agitating the protoxide in a saturated solution of chloride of lime. It dissolves in none of the acids except the muriatic, and during its solution in that acid much chlorine gas is exhaled. Its specific gravity, as determined by Mr. Harepath, is 5·322.

According to the experiments of Rothoff, it contains 1½ times as much oxygen as the protoxide. Hence it consists of

1 atom cobalt	3·25
1½ atom oxygen	1·5
	———
	4·75

Its atomic weight is 4·75, and it resembles deutoxide of nickel in its constitution as it agrees with it in atomic weight.

* Ann. de Chim. xlii. 213.
† Annals of Philosophy (2d series), i. 250.

3. Leopold Gmelin is of opinion that the protoxide of cobalt does not dissolve in ammonia, except when there is an acid present, with which it may form a double salt. When a neutral salt of cobalt is treated with an excess of ammonia, the greater part of the cobalt is precipitated in the state of blue flocks, which remain undissolved if the mixture is kept in a close vessel. But if oxygen be admitted it is rapidly absorbed, the blue flocks assume a green colour and gradually disappear, while the solution assumes a brown colour. When the salt employed in this experiment is nitrate of cobalt, if we commit the ammoniacal solution to a 'rapid spontaneous' evaporation, brown coloured prisms with square bases appear. These crystals Gmelin considers as a compound of nitrate of ammonia and *cobaltate* of ammonia. The protoxide of cobalt, according to him, absorbs a quantity of oxygen equal to what it previously contained, and is thus converted into a new oxide possessed of acid properties, and which therefore he calls *cobaltic acid.*[*] This acid is obviously a compound of

1 atom cobalt	.	.	3·25
2 atoms oxygen	.	.	2
			5·25

I have observed part of these phenomena, but not the whole; which makes me hesitate about the existence of this new oxide. Farther researches are obviously necessary.

III. Davy found that cobalt burnt when gently heated in chlorine gas; but he did not examine the chloride formed. When muriate of cobalt is evaporated to dryness it leaves a light red mass, which when heated in a retort allows chloride of cobalt to sublime under the form of a blue coloured voluminous snow. This chloride gradually absorbs moisture from the atmosphere, and is converted into a solution of muriate of cobalt.[†] There can be no doubt from this that it is a compound of

1 atom cobalt	.	.	3·25
1 atom chlorine	.	.	4·5
			7·75

It is the solution of this chloride that constitutes the celebrated sympathetic ink of Hellot. Letters made by it have a

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[*] Annals of Philosophy (2d series), ix. 69; or Schweigger's Jahrbuch, vi. 235.

[†] Proust.

red colour while moist; but when the paper is dried the cha-
racters become *blue.*

IV. Neither the bromide nor iodide of cobalt has been
hitherto examined. We are not acquainted with any com-
pounds which it may be capable of forming with hydrogen,
azote, carbon, boron, or silicon.

V. Phosphuret of cobalt may be formed by heating the metal *Phosphuret.*
red-hot, and then gradually dropping in small bits of phospho-
rus. It contains about $\frac{1}{15}$th of phosphorus. It is white and
brittle; and when exposed to the air, soon loses its metallic
lustre. The phosphorus is separated by heat, and the cobalt is
at the same time oxidated. This phosphuret is much more
fusible than pure cobalt.*

VI. Sulphur readily unites to cobalt, and from the researches *Sulphurets.*
which have been made, it appears that they combine in three
proportions, forming a *sulphuret, sesquisulphuret,* and *bisulphuret*
of cobalt.

1. Sulphuret of cobalt may be formed by various processes. *1. Sulphuret.*
Berthier obtained it by exposing sulphate of cobalt in a char-
coal crucible to a white heat. It is formed also when a neutral
salt of cobalt is mixed with a hydrosulphuret. The sulphuret
of cobalt in that case is thrown down in black flocks. Proust
obtained it by heating to redness a mixture of oxide of cobalt
and sulphur. This sulphuret has a yellowish white colour,
with the metallic lustre, and possesses the property of being
attracted by the magnet. It has not been accurately analyzed.
But there can be no doubt that it is a compound of

1 atom cobalt	. .	3·25
1 atom sulphur	. .	2
		5·25

2. Sesquisulphuret of cobalt was first formed by Arfvedson. *2. Sesquisul-*
He passed a current of dry hydrogen gas over anhydrous sul- *phuret.*
phate of cobalt heated to redness in a glass tube. Half the
oxide was reduced to the metallic state, and half the sulphur
expelled. The residual matter consisted of

1 atom oxide of cobalt,
1 atom sulphuret of cobalt,

probably united together and constituting a dark gray cohering
mass, which dissolved nearly in muriatic acid without the evo-
lution of gas. When heated a little sulphuretted hydrogen gas

* Pelletier; Ann. de Chim. xiii. 134.

'was disengaged. The undissolved portion when heated gave out sulphur, and oxide of cobalt remained. A current of dry sulphuretted hydrogen gas being passed over this matter, heated to redness in a glass tube, water was given out, and a sulphuret formed composed of

<div style="text-align:center">

1 atom cobalt   .   .   3·25

1½ atom sulphur   .   .   3

———

6·25*

</div>

Berzelius informs us that the same sesquisulphuret of cobalt is formed when the deutoxide of cobalt is gently heated in sulphuretted hydrogen gas. •And from Hisinger's analysis of cobalt pyrites from Riddarhyttan, it appears that it exists native.† It is a brittle substance of a dark gray colour.

3. Bisulphuret.   3. When the sesquisulphuret of cobalt is digested in muriatic acid, one-fourth of the cobalt is dissolved and a bisulphuret of cobalt remains. M. Setterberg succeeded also in forming the same bisulphuret, by mixing together 1 part of carbonate of cobalt, and 1½ of sulphur, and heating the mixture in a small glass retort, taking care that the temperature was much below a red heat. Water, carbonic acid, and sulphurous acid were given out, and bisulphuret remained. This bisulphuret is a black powder, destitute of lustre. It is not acted on by alkalies nor acids with the exception of nitric acid and aqua regia. At a red heat it gives out sulphur, and is converted into sesquisulphuret. It is evident from Setterberg's analysis that it is a compound of

<div style="text-align:center">

1 atom cobalt   .   .   3·25

2 atoms sulphur   .   .   4

———

7·25‡

</div>

VII. Cobalt readily absorbs selenium when assisted by heat. When the compound is heated to redness, it melts, gives out its excess of selenium, and forms a gray coloured mass, having the metallic lustre, and a foliated fracture.§

Arseniet.   VIII. When a mixture of 2 parts of cobalt in powder, and 3 parts of arsenic in powder are heated, they combine with the evolution of a red light into a blackish-gray porous mass.||

The affinity between cobalt and arsenic is strong. Almost

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* Arfvedson ; Annals of Philosophy (2d series), vii. 337.
† Afhandlingar, iii. 316.   ‡ Kong. Vetens. Acad. Handl. 1825, p. 211.
§ Ann. de Chim. lx. 272. || Gehlen.

all the native cobalt ores contain arsenic. It is found native, combined with arsenic in three proportions forming a sesquar-seniet, binarseniet, and terarseniet of cobalt. These ores have been described by mineralogists, though they do not seem to be aware of the nature of their respective compounds.

IX. One part of cobalt powder and two parts of antimony unite when heated into an iron-gray substance, which exhibits the metallic lustre when burnished.*

•X. Equal parts of cobalt and molybdenum melted into a button of a gray colour, brittle, and of difficult fusion. Two parts of cobalt and four of molybdenum gave an alloy of a sparkling reddish-gray colour, hard, brittle, not attracted by the magnet, internally granular, and of a bluish-gray colour.†

XI. The alloy of iron and cobalt is very hard, and not easily broken. Cobalt generally contains some iron, from which it is with great difficulty separated.

The remaining combinations of this metal with simple bodies are still unknown.

FAMILY IV. EASILY FUSIBLE BASES.

This family contains eight metals, which are all easily reduced to the metallic state. Indeed the greater number of them melt at a heat either below or very little above the commencement of ignition. They may all be fused in a common fire except copper; and even copper may be melted in a common fire when urged by bellows. They are precipitated from their solutions in acids in the metallic state in the order according to which they are placed in the following sections. Zinc precipitates all the others, but is not itself precipitated by any of them. Lead precipitates all except zinc and cadmium. Tin all except zinc and lead. Copper precipitates only bismuth, mercury, and silver; and mercury precipitates only silver. Silver is precipitated by all the rest, but does not itself precipitate any of the others. These eight metals will constitute the subject of the eight following sections.

SECTION I.—OF ZINC.

The ancients were acquainted with a mineral to which they gave the name of *Cadmia*, from Cadmus, who first taught the Greeks to use it. They knew that when melted with copper it formed brass; and that when burnt a white spongy kind of

History.

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* Gehlen.   † Crell's Annals, p. 371.

ashes was volatilized, which they used in medicine.* This mineral contained a good deal of zinc; and yet there is no proof remaining that the ancient Greeks and Romans were acquainted with this metal.† But there are strong reasons for believing that it was known at a very early period in China. The Chinese were acquainted with the method of rendering it malleable, and they struck pieces of money of it. Kaswini, the Pliny of the Arabians, at least states these circumstances as facts. The Arabians called it *Rouh-tutia*, and the Persians *Kar-tsini* (*Chinese iron*). According to Kaswini, mirrors were made of it which were considered as useful in curing sore eyes.‡ Albertus Magnus describes the ore of zinc in his Mineralogy under the name of *marchasite of gold*, and it is evident from his account of it that he was aware of its containing a volatile metal. The word zinc (*zinetum*) so far as I have observed, occurs first in Paracelsus, and he mentions it as if it had been a familiar word at the time when he wrote.§

Zinc has never been found in Europe in a state of purity, and it was long before a method was discovered of extracting it from its ore.‖ Henkel pointed out one in 1721; Von Swab obtained it by distillation in 1742; and Margraff published a process in the Berlin Memoirs in 1746.¶ At present there are several works in this country in which zinc is extracted from its ore, chiefly in Birmingham and Bristol. There was a work some years ago near Alston Moor, but it has been stopped. Both calamine and blende are employed. The calamine is sometimes roasted, sometimes not; it is reduced to fragments about the size of a pigeon's egg, and introduced with its own

* Pliny, lib. xxxiv. cap. 2 and 10.

† Grignon indeed says, that something like it was discovered in the ruins of an ancient Roman city in Champagne: but the substance which he took for it was not examined with any accuracy. It is impossible therefore to draw any inference whatever from his assertion. Bulletin de Fouilles d'une Ville Romaine, p. 11.

‡ Schweigger's Jahrbuch, i. 357.

§ Quando ergo hoc modo metalla fiunt et producuntur, dum scilicet verus metallicus fluxus et ductilitas aufertur, et in septem metalla distribuitur: residentia quædam manet in ares, instar fœtûm trium primorum. Ex hac nascitur *zinetum*, quod et metallum est et non est. Sic et bisemutum et huic similia alia portim fluida partim ductilia sunt. . . . Zinetum maxima ex parte spuria soboles est de cupro, et bisemutum de stanno. Philosophiæ, lib. iv. Tract. iii. cap. 9.

‖ The real discoverer of this method appears to have been Dr. Isaac Lawson. See Pott, iii. diss. 7, and Watson's Chemical Essays.

¶ Bergman, ii. 309.

volume of small coal into clay pots or crucibles, which are arranged
six in number round a circular furnace, vaulted above. There is
a hole in the bottom of each pot which is partly closed with a
piece of wood, and from which a tube of iron passes to a vessel
of water, situated in an apartment below. The pots are left
open for about two hours till the flame begins to assume a blue
colour, indicating that the zinc is beginning to be reduced.
They are then covered up on the top. The zinc is reduced,
and gradually drops down through the iron tube issuing from
the bottom of the pot, and falls into a vessel of water. It
is afterwards melted and cast into ingots. A considerable
quantity of zinc is yearly exported from Britain, chiefly to
the north of Europe.* The process when blende (sulphuret
of zinc) is used, is quite the same; except that the blende is
always roasted in the first place.

I. Zinc is of a brilliant white colour, with a shade of blue, Properties.
and is composed of a number of thin plates adhering together.
When this metal is rubbed for some time between the fingers,
they acquire a peculiar taste, and emit a very perceptible smell.

It is rather soft: when rubbed upon the fingers it tinges
them of a black colour. The specific gravity of melted zinc
varies from 6·861 to 7·1 ;† the lightest being esteemed the
purest. When hammered it becomes as high as 7·1908.‡ I
found the specific gravity of a specimen which I had purified,
by distilling it over in a porcelain retort, 6·89655.

This metal forms as it were the limit between the brittle and
the malleable metals. Its malleability is by no means to be
compared with that of copper, lead, or tin ; yet it is not brittle,
like antimony or arsenic. When struck with a hammer, it does
not break, but yields, and becomes somewhat flatter; and by a
cautious and equal pressure, it may be reduced to pretty thin
plates, which are supple and elastic, but cannot be folded with-
out breaking. This property of zinc was first ascertained by
Mr. Sage.§ When heated somewhat above 212°, it becomes
very malleable. It may be beat at pleasure without breaking,
and hammered out into thin plates. When carefully annealed,

* See an account of the manufacture of this metal in Watson's Chem.
Essays, iv. 1.

† Brisson and Dr. Lewis. A specimen of Goslar zinc was found by Dr.
Watson of the specific gravity 6·953, Bristol zinc 7·028. Chemical Essays,
iv. 41. A specimen of zinc tried by Mr. Hatchett was 7.065. On the
Alloys of Gold, p. 67.

‡ Brisson. § Jour. de Min. An. v. 595.

it may be passed through rollers. It may be very readily turned on the lathe. When heated to about 400°, it becomes so brittle that it may be reduced to powder in a mortar.

It possesses a certain degree of ductility, and may with care be drawn out into wire.* Its tenacity, from the experiments of Muschenbroeck, is such, that a wire whose diameter is equal to $\frac{1}{10}$th of an inch is capable of supporting a weight of about 26 lbs.†

When heated to the temperature of about 680°,‡ it melts; and if the heat be increased, it evaporates, and may be easily distilled over in close vessels. When allowed to cool slowly, it crystallizes in small bundles of quadrangular prisms, disposed in all directions. If they are exposed to the air while hot, they assume a blue changeable colour.§

Oxide. II. When exposed to the air, its lustre is soon tarnished, but it scarcely undergoes any other change. When kept under water, its surface soon becomes black, the water is slowly decomposed, hydrogen gas is emitted, and the oxygen combines with the metal. If the heat be increased, the decomposition goes on more rapidly; and if the steam of water is made to pass over zinc at a very high temperature, it is decomposed with great rapidity.||

When zinc is kept melted in an open vessel, its surface is soon covered with a gray coloured pellicle, in consequence of its combination with oxygen. When this pellicle is removed, another soon succeeds it; and in this manner may the whole of the zinc be oxidized. When these pellicles are heated and agitated in an open vessel, they soon assume the form of a gray powder, often having a shade of yellow. This powder has been called the *gray oxide of zinc,* but is probably only a mixture of white oxide and metallic zinc. When zinc is raised to a strong red heat in an open vessel, it takes fire, and burns with a brilliant white flame, and at the same time emits a vast quantity of very light white flakes. These are merely an *oxide of zinc.* This oxide was well known to the ancients. Dioscorides describes the method of preparing it. The ancients called it *pompholyx :* the early chemists gave it the name of *nihil album,*

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* Black's Lectures, ii. 583.

† He found a rod of an inch diameter to support 2600 lbs. Now if the cohesion increase as the square of the diameter, the strength of a wire of 1-10th inch will not differ much from that assigned in the text.

‡ Black's Lectures, ii. 583.   § Mongez.

|| Lavoisier, Mem. Par. 1781, p. 274.

lana philosophica, and *flowers of zinc.* Dioscorides compares it to wool.*

So far as has been hitherto proved, this is the only oxide of zinc. It is not easy to procure it quite free from iron, with which the zinc of commerce is always contaminated. The iron may be thrown down by leaving a plate of zinc in an aqueous solution of sulphate or muriate of zinc for a few weeks. Probably also we would obtain the oxide pure, if we dissolved it in caustic ammonia, and after filtering the solution, we were to drive off the ammonia by heat, and collect the oxide which would precipitate.

Oxide of zinc when pure is snow-white. When heated it assumes a yellow colour, but becomes again white when allowed to cool. It is tasteless; but dissolves very readily in acids. It dissolves also in concentrated caustic ammonia, but is partly precipitated when the solution is diluted with water. Barytes or lime water also occasion a precipitate when poured into the same solution. The affinity between oxide of zinc and alumina is considerable. When a solution of oxide of zinc in ammonia, and of alumina in caustic potash, are mixed together, the oxide of zinc and alumina are precipitated in combination; the precipitate is again redissolved by an excess of either of the alkalies. This compound occurs in the mineral kingdom, and is distinguished by the names of *automalite* and *Gahnite.* It consists of 6 atoms of alumina united to 1 atom of oxide of zinc.

I ascertained, by the analysis of sulphate of zinc, that the atomic weight of oxide of zinc is 5·25, and that when 4·25 of metallic zinc are dissolved in sulphuric acid, they are converted into 5·25 parts of oxide of zinc.†

It has been inferred from an experiment of Thenard, that when oxide of zinc in the gelatinous state is treated with deutoxide of hydrogen, it combines with an additional dose of oxygen. The new oxide is described as white and tasteless. It cannot be dried nor dissolved in acids, without losing its excess of oxygen. I do not see any sufficient proof that in this case there is any thing more than a mixture of oxide of zinc and deutoxide of hydrogen.

The reduction of the oxides of zinc is an operation of difficulty, in consequence of the strong affinity which exists between zinc and oxygen, and the consequent tendency of the zinc after reduction to unite with oxygen. It must be mixed with charcoal, and exposed to strong heat in vessels which screen it from the contact of the external air.

Atomic weight.

* Εριον τολυπαι αφομοιονται, V. 85, p. 352. † First Principles, i. 51.

III. Zinc combines readily with chlorine and forms a *chloride of zinc*. This metal takes fire in chlorine gas, and the chloride is formed. It may be obtained by dissolving zinc in muriatic acid, evaporating the solution to dryness, and exposing it to a red heat in a glass tube with a narrow orifice. When obtained by distilling a mixture of zinc filings and corrosive sublimate it was formerly distinguished by the name of *butter of zinc*. When obtained in this way it sublimes readily on being heated, and crystallizes in needles. But Dr. John Davy assures us that when the chloride is formed by heating the muriate in a glass tube it does not sublime even at a red heat; but remains in a state of fusion. When exposed to the air it very speedily deliquesces.

Dr. John Davy found it composed of equal weights of zinc and chlorine. It is obvious from this that it is a compound of

1 atom zinc	4·25
1 atom chlorine	4·5
	8·75

and that its atomic weight is 8·75.

IV. The bromide of zinc has not yet been examined.

V. Zinc readily combines with iodine by heat. The iodide has a white colour. It is easily volatilized and crystallizes in fine quadrangular prisms. It deliquesces in the air and is very soluble in water. The solution is colourless and does not crystallize. This solution contains a combination of hydriodic acid and oxide of zinc. Hence the iodide must decompose water. Gay-Lussac has shown that this iodide is a compound of

1 atom zinc	4·25
1 atom iodine	15·75
	20

so that its atomic weight is 20.

VI. Professor Kastner affirms, that when zinc is dissolved in moderately strong muriatic acid, the hydrogen gas given off contains zinc in solution.* If this be so, certainly the quantity must be very small, for I have more than once burnt such hydrogen gas without perceiving any deposite of oxide of zinc. Vauquelin formed a gas by heating to redness 4 parts of roasted blende and 1 part of charcoal powder, which he considered as *zincetted hydrogen gas*. It was colourless, lighter than air, but heavier than hydrogen gas. It burnt with a bluish and yellowish

* Annals of Philosophy (2d series), iv. 157.

flame, giving out white vapours of oxide of zinc, and deposit-
ing some metallic zinc. It burnt with chlorine gas, and was
converted into muriatic acid and chloride of zinc. It was not
decomposed by nitric acid, it was not absorbed by water, and
did not combine with bases.

We do not know any combination which zinc is capable of
making with azote.

VII. The zinc of commerce is never free from carbon ; but
as it contains iron also, we have no evidence that the small
quantity of carbon which it contains is not in combination with
the iron. Berzelius considers the black matter which remains,
when prussiate of zinc is distilled, as a carburet of zinc. But
he has adduced no evidence in favour of this opinion.

VIII. Nothing is known respecting the combinations which
zinc may be capable of forming with boron and silicon.

IX. Zinc may be combined with phosphorus, by dropping Phosphuret.
small bits of phosphorus into it while in a state of fusion. Pel-
letier, to whom we are indebted for the experiment, added also
a little resin, to prevent the oxidation of the zinc. Phosphuret
of zinc is of a white colour, with a metallic splendour, but
resembles lead more than zinc. It is somewhat malleable.
When hammered or filed, it emits the odour of phosphorus.
When exposed to a strong heat, it burns like zinc.* When
12 parts of oxide of zinc, 12 parts of phosphoric glass, and 2
parts of charcoal powder, are distilled in an earthenware retort,
and a strong heat applied, a metallic substance sublimes of a
silver-white colour, which when broken has a vitreous appear-
ance. This, according to Pelletier, is phosphuretted oxide of
zinc, but it is probably only a phosphuret of zinc. When
heated by the blow-pipe, the phosphorus burns, and leaves
behind a glass, transparent while in fusion, but opaque after
cooling.† It is obtained also when 2 parts of zinc and 1 part
of phosphorus are distilled in an earthen retort. The products
are, 1. Zinc ; 2. Oxide of zinc ; 3. A red sublimate, which is
phosphuretted zinc ; 4. Needleform crystals, of a metallic bril-
liancy and a bluish colour. These Pelletier considers as phos-
phuretted oxide of zinc.‡ They are probably a phosphuret of
zinc.

X. Chemists were long unable to combine zinc with sulphur; Sulphuret.
but several processes have been gradually discovered. Mr.
Edmond Davy found that when the vapour of sulphur was

* Ann. de Chim. xiii. 129.   † Pelletier, ibid. 128.   ‡ Ibid. 125.

'passed over zinc in fusion, a yellowish compound was obtained similar in appearance to blende. When the oxide of zinc is melted with sulphur a combination is formed, as was first discovered by Dehne in 1781.* The experiment was afterwards repeated by Morveau.† When zinc and cinnabar are heated together, according to Berzelius, the mercury of the cinnabar is disengaged and sulphuret of zinc formed. When a current of sulphuretted hydrogen is passed through a solution of zinc a white precipitate falls, which is a hydrosulphuret of zinc. When this hydrosulphuret of zinc is carefully heated it is converted into sulphuret of zinc. ' I dissolved 42·5 grains of zinc in sulphuric acid, passed a current of sulphuretted hydrogen gas through it, and then heated the hydrosulphuret. The weight of the sulphuret of zinc obtained was very nearly 62·5.

One of the most common ores of zinc is a foliated mineral, usually of a brown colour, called *blende;* tasteless, insoluble in water, and of a specific gravity about 4. Bergman showed that this ore consisted chiefly of zinc and sulphur. Chemists were disposed to consider it as a sulphuretted oxide of zinc, in consequence chiefly of the experiments of Morveau, above referred to; but the analyses of Bergman were inconsistent with this notion. Proust gave it as his opinion, that blende is essentially a compound of zinc in the metallic state with sulphur.‡ This opinion is now universally admitted to be the true one. It is a compound of

1 atom zinc	4·25
1 atom sulphur	2
	6·25

But in general it contains a quantity of iron. The only pure specimens are the transparent and light brown ones.

It has the lustre of the diamond, is translucent, of a rich yellow colour, and is crystallized in rhomboidal dodecahedrons. It is brittle, has a foliated texture and a specific gravity of 4·678. It dissolves with difficulty in muriatic acid, giving out sulphuretted hydrogen gas. Aqua regia dissolves it easily. It melts when exposed to a high temperature.

The experiments of Arfvedson on the change produced by passing a current of dry hydrogen gas over ignited sulphate of zinc, were unsatisfactory.§ But it appears from the observations

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* Chem. Jour. p. 46, and Crell's Annals, 1786, i. 7.
† Mem. de l'Acad. de. Dijon, 1783.   ‡ Jour. de Phys. lvi. 79.
§ Annals of Philosophy (2d series), vii. 335.

of Kersten, that several sulphurets, particularly those of iron and zinc, are treated at Freyberg to extract the silver. During this operation there is deposited a yellow matter having the diamond lustre in six-sided prisms. This matter Kersten found composed of

4 atoms sulphuret of zinc,
1 atom oxide of zinc.*

XI. It is equally difficult to combine zinc with selenium as Seleniet. with sulphur. But if red hot zinc be brought in contact with the vapours of selenium, an explosion takes place and a yellow powder is formed, which is a seleniet of zinc. This powder dissolves in nitric acid with the evolution of nitrous gas. The zinc is oxidized and dissolved while the selenium separates in the state of a red powder.†

XII. When 100 parts of zinc and 100 parts of arsenic are Arseniet. heated, a very brittle metal is obtained weighing 172 parts.‡ If the loss in this experiment was all arsenic the alloy was very nearly a compound of

1 atom arsenic,
1½ atom zinc.

According to Bergman when zinc and arsenious acid are distilled, a process first practised by Malouin, an alloy is obtained composed of four parts of zinc and one of arsenic.

XIII. Zinc may be readily combined with antimony by fusion. The alloy is hard and brittle, and has the colour of steel. Its specific gravity is less than intermediate.§

XIV. Nothing is known respecting the alloys which zinc may be capable of forming with tellurium, chromium, tungsten, columbium, and titanium.

XV. The volatility of zinc renders it difficult to alloy that metal with molybdenum. Equal parts of the two metals, strongly heated in a covered crucible, left a black mass almost in a powdery state.||

XVI. Zinc may be alloyed with potassium by heat; but the alloy is difficult to form on account of the volatility of the potassium. It has the colour of pounded zinc. It is gradually destroyed in the air, effervesces in water, and still more violently in acids.¶

With sodium it is easily alloyed in a cherry-red heat. The

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* Ann. de Chim. et de Phys. xli. 426.   † Berzelius, ibid. x. 241.
‡ Gehlen.   § Gellert, p. 136.
|| Crell's Annals, iii. p. 375.
¶ Gay-Lussac and Thenard; Recherches Physico-chimiques, i. 221.

colour of the alloy is bluish-gray. It is brittle, and of a foliated texture. It is destroyed in the air, and effervesces in water and in acids.*

XVII. We are not acquainted with the alloys which zinc forms with the metals of the alkaline earths and earths proper.

XVIII. It is difficult to combine zinc with iron, because the heat necessary to melt the latter metal dissipates the former. The alloy, according to Lewis, when formed, is hard, somewhat malleable, and of a white colour approaching to that of silver.† Malouin has shown that zinc may be used instead of tin to cover iron plates: a proof that there is an affinity between the two metals.‡

XIX. Zinc does not appear capable of combining with nickel by fusion.§ Neither does it combine with cobalt by fusion.

We are not acquainted with the alloys which zinc may be capable of forming with manganese, cerium, and uranium.

SECTION II.—OF CADMIUM.

History.   Professor Stromeyer of Gottingen, whose province it is to inspect the apothecaries' shops in the kingdom of Hanover, while discharging the duties of his office in the principality of Hildesheim in the year 1817, found that the carbonate of zinc was substituted in that country for the oxide of zinc, the use of which had been ordered in the Pharmacopœias. This carbonate of zinc was manufactured at Salzgitter. Upon inquiry he learnt from Mr. Jost, who managed that manufactory, that they had been obliged to substitute the carbonate for the oxide of zinc, because the oxide had a yellow colour, and was in consequence unsaleable. On examining this oxide, Stromeyer found that it owed its yellow colour to the presence of a small quantity of the oxide of a new metal, which he separated, reduced, and examined. To the metal thus obtained he gave the name of *cadmium*, because it occurs usually associated with zinc.

During the apothecaries' visitation, in the state of Magdeburg some years ago, there was found in the possession of several apothecaries, a preparation of zinc from Silesia, made in Hermann's manufactory at Schönebeck, which was confiscated

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* Gay-Lussac and Thenard; Recherches Physico-chimiques, i. 243.
† Neuman's Chem. p. 69.   ‡ Mem. Par. 1742.
§ The Chinese, however, seem to be in possession of some method of combining these metals; for, according to Engestroem, the *pak-fong* or white copper, is composed of copper, nickel, and zinc. The zinc amounts to seven-sixteenths of the whole, and the proportions of the copper and nickel are to each other as five to thirteen. Mem. Stock. 1776.

on the supposition that it contained arsenic; because when dis-
solved in acids and mixed with sulphuretted hydrogen, it let
fall a precipitate, which, from some experiments made on it,
was considered as orpiment.   This fact could not be indifferent
to Mr. Hermann, as it affected the credit of his manufactory;
and the more especially as the medical councellor Roloff, who
had assisted at the apothecaries' visitation, had drawn up a state-
ment of the whole and sent it to Hofeland in Berlin, who pub-
lished it in his Medical Journal.   Hermann in consequence
subjected the suspected oxide of zinc to a careful examination;
but he could not succeed in detecting any arsenic in it.   He
then requested the medicinal councellor Roloff to repeat his
experiments on the oxide once more. This he did very readily;
and he now perceived that the precipitate, which had been taken
by him at first for orpiment, was not so in reality, but owed its
existence to the presence of another metal, having considerable
resemblance to arsenic, but probably new.   To obtain full cer-
tainty on the subject, specimens of the oxide of zinc, and of the
yellow precipitate, were sent to Stromeyer; who immediately
recognised in them the presence of cadmium, in a considerably
greater proportion (about 3 per cent.) than in the oxide which
he had previously examined.   This fortunately enabled him to
procure a sufficient quantity of cadmium to examine its proper-
ties in detail.*

Professor Stromeyer separated the cadmium from the oxide of
zinc with which it was mixed in the following manner: The
whole is dissolved in sulphuric acid, and an excess of that acid
being added to the solution, a current of sulphuretted hydrogen
gas is passed through the liquid till the whole of the cadmium
is precipitated.   It falls along with a portion of zinc and of cop-
per, if any happen to be present.   The precipitate is redissolved
in concentrated muriatic acid, and the excess of acid driven off
by evaporation.   The liquid is now mixed with an excess of
carbonate of ammonia.   The whole of the zinc and the copper
is redissolved, while the carbonate of cadmium is precipitated
and remains in the state of a powder.   By exposing this carbo-
nate to a red heat, it is converted into pure oxide of cadmium.
This oxide being mixed with lamp black and exposed to a
moderate red heat in an earthen or glass retort, the cadmium is
reduced to the metallic state.

Mr. Harepath of Bristol ascertained that the yellowish brown
sublimate which adheres to the roof of the apartment in which

* Stromeyer, Annals of Philosophy, xiii. 108.

zinc is smelted at Bristol, contained a great deal of cadmium. He was kind enough to send me a quantity of this sublimate. I found that it contained about 10 per cent of cadmium. To obtain the cadmium I digested it in sulphuric acid, and put a plate of zinc into the solution. The cadmium was precipitated in the metallic state. Dr. Wollaston observed that when the solution containing the cadmium is put into a platinum crucible, and the plate of zinc suspended in it, the precipitated cadmium adheres so strongly to the crucible that it may be washed with water without any risk of loss. It may then be dissolved in an acid and its properties dettrmined. I find it to exist in minute quantity in metallic zinc.

Properties.　I. Cadmium thus obtained has a white colour, with a very slight shade of bluish-gray, and approaches nearest to tin in this respect. It has a good deal of brilliancy, and may be made to assume a fine polish. Its fracture is hackly; and it readily crystallizes in regular octahedrons.

It is a soft metal; being easily acted on by the file, or cut with the knife. It is very malleable, and may be beat out under the hammer into very thin plates. It may be likewise drawn out into wire. Its specific gravity, after fusion, is 8·6040; but after hammering it becomes as high as 8·6944. According to Mr. Harepath it is 8·659.* It is very fusible; melting before it becomes red-hot. It may be melted by touching it with an iron wire heated to redness by means of a spirit lamp. It is also very volatile, being converted into vapour at a temperature somewhat higher than the boiling point of mercury. This vapour has no peculiar smell. It collects in drops like mercury, and crystallizes as it cools.

Oxide.　II. When exposed to the air this metal is as little altered as zinc; though in progress of time its surface becomes tarnished. When heated in the open air it catches fire as easily as zinc, and is changed into a brownish-yellow coloured oxide, which usually flies off in the state of a brownish-yellow smoke, and coats those substances that are held over the burning metal. Even when thus burnt it gives out no perceptible smell.

The metal dissolves slowly in sulphuric, muriatic, and acetic acids, with the evolution of hydrogen gas. It dissolves readily in nitric acid, while nitrous gas is disengaged. In all cases it combines with the same proportion of oxygen, forming only one oxide, which has a yellow colour, is fixed in the fire, and infusible in a white heat.

* Phil. Mag. lxiv. 322.

From the analyses of carbonate, sulphate, and nitrate of cadmium, by Stromeyer, we obtain as a mean the atomic weight of this oxide 8·015. I have shown, by the analysis of sulphate of cadmium in two different states, that the true atomic weight is 8.* Now, as the metal forms only one oxide, it is obvious that it must be a compound of

1 atom cadmium	.	.	7
1 atom oxygen	.	.	1
			—
			8

and that the atomic weight of cadmium is 7.

This oxide is insoluble in the caustic fixed alkalies; but dissolves readily in ammonia. It is insoluble in carbonate of ammonia, which distinguishes it from oxide of zinc. When sulphuretted hydrogen gas is passed through its solution a fine yellow precipitate falls, which was at first taken for orpiment. The specific gravity of oxide of cadmium is, according to Mr. Harepath, 8·183.† It may be precipitated from its solutions in the state of a gelatinous hydrate.

The colour of this oxide varies according to the degree of heat to which it has been exposed, being brownish-yellow, light-brown, dark-brown, or blackish. It is exceedingly easily reduced when heated in contact with charcoal. It is insoluble in water; but it combines with that liquid and forms a white coloured hydrate, which speedily absorbs carbonic acid when exposed to the air.

It saturates the different acids, and forms with them neutral salts.

III. When oxide of cadmium is dissolved in muriatic acid, Chloride. and the solution evaporated, small transparent rectangular crystals of muriate of cadmium are obtained. When these crystals are heated they lose their water of crystallization and are converted into a transparent foliated crystallized mass, having a pearly lustre inclining somewhat to the metallic. This matter may be considered as a chloride of cadmium. When exposed to the air it falls down in the state of a white powder. When strongly heated it sublimes in the state of micaceous plates, having the original transparency and lustre, and not altering when exposed to the air. From the analysis of Stromeyer,‡ this chloride is obviously composed of

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* First Principles, i. 391.   † Phil. Mag. lxiv. 322.
‡ Gilbert's Annalen, lx. 204.

1 atom chlorine	.	.	4·5
1 atom cadmium	.	.	7·
			11·5

Iodide.   IV. Cadmium combines readily with iodine, either by heating the two substances together, or by boiling them in water till a solution is obtained. By evaporating this solution we obtain crystals in fine six-sided tables, possessing nearly the properties of the iodide, formed by heating the two constituents directly together. These crystals have a white colour, are transparent, and not altered by exposure to the air. Their lustre is metallic, with a tendency to the pearly. They melt very easily when heated, and assume on cooling their former crystalline form. When they are strongly heated, the iodine is gradually driven off. They dissolve easily in water and alcohol, and may be again obtained in crystals by evaporating these liquids. From these solutions the cadmium may be precipitated in the state of a carbonate by the alkaline carbonates. It is thrown down likewise by sulphuretted hydrogen gas. It is obvious that these crystals, when in solution, constitute a hydriodate of cadmium; but an iodide of cadmium when in the dry state. The iodide, from the experiments of Stromeyer,* is obviously composed of

1 atom cadmium	.	.	7
1 atom iodine	.	.	15·75
			22.75

V. Cadmium does not seem capable of combining with azote or hydrogen. Nothing is known respecting any combination of this metal with carbon, boron, silicon, or selenium. But it unites readily with sulphur, and forms a sulphuret which has been particularly examined by Stromeyer.

Sulphuret.   Sulphur and cadmium unite only in one proportion, and the sulphuret, when acted on by nitric acid, is converted into a neutral sulphate of cadmium. Hence it is obviously a compound of 1 atom cadmium + 1 atom of sulphur, or of

Cadmium	.	.	7
Sulphur	.	.	2

This sulphuret has a yellow colour, inclining to orange. When reduced to powder, it has a very fine orange-yellow colour. When heated to redness, it becomes first brown and

* Gilbert's Annalen, lx. 207.

then carmine red; but on cooling it resumes its original colour. It bears a very strong heat without undergoing any change. But in an intense white heat it melts and crystallizes in transparent micaceous plates of a fine yellow colour. It dissolves readily in concentrated muriatic acid, while sulphuretted hydrogen gas is disengaged, and no sulphur whatever is deposited. But diluted muriatic acid hardly acts upon it even when assisted by heat.

• Sulphur and cadmium cannot be easily united by exposing them to heat mixed together. We succeed better when we heat a mixture of oxide of cadmium and sulphur. But the easier method of forming the sulphuret is to precipitate a salt of cadmium by means of sulphuretted hydrogen gas. This sulphuret constitutes an excellent paint.*

VI. Phosphuret of cadmium is gray and has a weak metallic Phosphuret. lustre; it is very brittle and melts with great facility. On burning coals it burns brilliantly with a strong smell of phosphorus, and is converted into phosphate of cadmium.

None of the combinations of cadmium and metals have been hitherto examined, excepting the alloys which it forms with copper, mercury, and platinum. These will be described in a subsequent part of this volume.

Cadmium is precipitated in the metallic state by a plate of zinc. But it has the property of precipitating lead, and all the other metals belonging to the family under which I have placed it.

SECTION III.—OF LEAD.

Lead appears to have been very early known. It is men- History. tioned several times by Moses. The ancients seem to have considered it as nearly related to tin.

Lead is one of the most abundant of metals, and exists in the earth in a great variety of states; no fewer than 27 different species of lead ores having been described by mineralogists. But by far the most abundant of these ores, indeed the only important one, as far as metallurgy is concerned, is *sulphuret of lead*, or *galena*, a lead coloured mineral, having the metallic lustre, a foliated texture, crystallized in cubes or octahedrons, and having a specific gravity of 7·568. In Great Britain, by far the most abundant lead mines occur in the mountain limestone, or rather limestone that alternates with

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* Stromeyer, Gilbert's Annalen, lx. 205.

the coal-beds. They occur also in the transition formations, while at Strontian and in Cornwall they occur in primary rocks.

The galena is first roasted in a large reverberatory furnace. A white smoke rises, which is condensed in a long horizontal chimney. I was surprised, on examining this matter, to find that it consisted chiefly of sulphate of lead. By continuing the roasting the whole galena might be converted into sulphate of lead. But the process is never carried nearly so far. The roasted galena is now heated on a hearth with coal and a small quantity of limestone, which is added every now and then. The lead is reduced and collected in vessels, from which it is cast into large ingots called pigs. Sometimes the process is conducted in reverberatory furnaces, and sometimes in blast furnaces. The slag formed is run into water, which causes it to fall into powder, and this powder is again smelted to extract a little more lead.

The lead thus obtained is never free from silver. When the quantity of that metal is sufficient to pay the expense the silver is extracted, and this process is called refining the lead. Bone ashes, mixed with about $\frac{1}{16}$th of their weight of pearl ashes, are made into a thick mortar with water, and beat into a kind of oval iron ring, so as to form a large flat surface, scooped out a little on the upper side. This is called a cupel. The lead to be refined is put upon this cupel, in a reverberatory furnace, and exposed to the blast of a bellows placed conveniently for the purpose. The lead speedily melts, becomes red hot, and is oxidized, and the oxide, as it forms, is blown off the cupel by the blast, or sinks into it. The silver remains unaltered. When the lead left on the cupel becomes rich in silver it is taken off, and new lead put in its place. The process goes on till a sufficient number of masses of lead rich in silver are collected. These are put upon the cupel together, and the process of cupellation continued till the lead is all oxidized, and the silver remains pure.

The litharge thus formed is partly sold to the glass-makers, apothecaries, and other artists, who use it in their processes, and partly reduced again to the state of lead, by simply heating it on a hearth along with coal. Such is a very short and imperfect sketch of the mode of smelting lead employed in the North of England, Cumberland, Durham, and Yorkshire, where by far the greatest quantity of lead is smelted. The annual produce of lead in Great Britain amounts to about 32,000 tons.

But the price has of late years fallen so low that it does little more than pay the expense of the processes. The consequence must be that all but the most productive mines will be relinquished. This would be attended with great hardship to the miners, many thousands of whom are at present supported by working the lead mines in different parts of Great Britain.

I. Lead is of a bluish white colour; and when newly melted is very bright, but it soon becomes tarnished by exposure to the air. It has scarcely any taste, but emits on friction a peculiar smell. It stains paper or the fingers of a bluish colour. When taken internally it acts as a poison. Properties.

It is one of the softest of the metals, its specific gravity is 11·3523.* Mr. Harepath states it at 11·352,† and Mr. Crichton of Glasgow found the specific gravity of a very pure specimen 11·357. Its specific gravity is not increased by hammering; so far from it, that Muschenbroeck found lead when drawn out into a wire, or long hammered, actually diminished in its specific gravity. A specimen at first of the specific gravity 11·479, being drawn out into a fine wire, was of the specific gravity 11·317; and on being hammered, it became 11·2187; yet its tenacity was nearly tripled.‡ Guyton Morveau on repeating this experiment found the result as stated. But he found likewise that he could increase the specific gravity of lead, by hammering it, confined in a mould so that it had not liberty to expand.

It is very malleable, and may be reduced to thin plates by the hammer; it may be also drawn out into wire, but its ductility is not great. Its tenacity is such, that a lead wire $\frac{1}{10}$ inch diameter is capable of supporting only 18·4 pounds without breaking. This agrees nearly with Mr. Rennie's trials, who found a wire of lead $\frac{1}{4}$ inch diameter, capable of just supporting 114 lbs. Hence a wire $\frac{1}{10}$th inch in diameter, would just support 18·7 lbs.§

From the experiments of Crichton of Glasgow we learn that lead melts when heated to the temperature 612°.‖ When a very strong heat is applied the metal boils and evaporates. If

* Brisson. Fahrenheit found it 11·3500, Phil. Trans. 1724. vol. xxxiii. p. 114. I found a specimen of milled lead 11·407 at the temperature of 64°.
† Phil. Mag. lxiv. 322.   ‡ Wasserberg, i. 441.
§ Phil. Trans. 1818, p. 126.
‖ Phil. Mag. xvi. 49. Gay-Lussac states the melting point of lead to be 613°. Ann. de Chim. et de Phys. ix. 308. Mr. Crichton, jun., found the melting point of lead to be 606°.

it be cooled slowly, it crystallizes. The Abbé Mongez obtained it in quadrangular pyramids, lying on one of their sides. Each pyramid was composed, as it were, of three layers. Pajot obtained it in the form of a polyhedron with 32 sides, formed by the concourse of six quadrangular pyramids.*

Oxides.

II. When exposed to the air it soon loses its lustre, and acquires first a dirty gray colour, and at last its surface becomes almost white. This is owing to its gradual combination with oxygen, and conversion into an oxide. But this conversion is exceedingly slow; the external crust of oxide, which forms first, preserving the rest of the metal for a long time from the action of the air.

Water has no direct action upon lead; but it facilitates the action of the external air: for, when lead is exposed to the air, and kept constantly wet, it is oxidated much more rapidly than it otherwise would be. Hence the reason of the white crust which appears upon the sides of leaden vessels containing water, just at the place where the upper surface of the water usually terminates.

Protoxide.

Lead unites with oxygen in three portions, and forms the *protoxide* of lead, which is *yellow;* the *peroxide,* which is *brown;* and the *red oxide,* which is intermediate between the yellow and the brown.

1. The *protoxide* or *yellow oxide* of lead, which has been longest known, and most carefully examined, may be obtained by dissolving lead in a sufficient quantity of nitric acid, so as to form a colourless solution, and then supersaturating it with carbonate of potash. A white powder falls, which, when dried and heated nearly to redness, assumes a yellow colour. It is pure *yellow oxide of lead.* This oxide is tasteless, insoluble in water, but soluble in potash and in acids. Its specific gravity, as determined by Royet and Dumas, is 8·010.† Mr. Harepath states it as high as 9·277. Houton Labillardiere found that when it was dissolved in caustic soda, and left for some time in an open vessel, it gradually crystallized in regular dodecahedrons, which were not altered by exposure to a red heat, and therefore contained neither water nor carbonic acid.‡

It readily melts when heated, and forms a yellow, semi-transparent, brittle, hard glass. In violent heats a portion of

* Jour. de Phys. xxxviii. 53.
† Annals of Philosophy (2d series), iii. 392.
‡ Ann. de Chim. et de Phys. vii. 218.

it is dissipated. When kept heated in the open air, its surface becomes brick red.

Litharge, when formed from pure lead, consists entirely of protoxide, without any foreign substance whatever.* It is in beautiful red or yellow scales or flakes. When yellow oxide is prepared on a large scale by manufacturers, it is called *massicot*. It dissolves readily in nitric acid and acetic acid. It may be dissolved in boiling hot muriatic acid; but not in sulphuric nor phosphoric. It combines with oils, and forms plasters. It dissolves easily in the caustic fixed alkalies, but not in ammonia. Its solution in acetic acid is rendered muddy by carbonic acid. The solution of this oxide in acids is sweet tasted. Such solutions produce poisonous effects when taken internally.

By the analysis of nitrate and sulphate of lead I have shown that the atomic weight of protoxide of lead is 14.† By dissolving a given weight of lead in nitric acid, evaporating the solution to dryness, and weighing the salt, it is easy to show that this oxide is a compound of

1 atom lead	. . .	13
1 atom oxygen	. .	1
		—
		14·

consequently the atomic weight of lead is 13.

When lead is kept melted in an open vessel, its surface is soon covered with a gray coloured pellicle. When this pellicle is removed, another succeeds it; and by continuing the heat the whole of the lead may soon be converted into this substance. If these pellicles be heated and agitated for a short time in an open vessel, they assume the form of a greenish yellow powder. Mr. Proust has shown that this powder is a mixture of yellow oxide and a portion of lead in the metallic state. It owes its green colour to the blue and yellow powders which are mixed in it. If we continue to expose this powder to heat for some time longer in an open vessel, it absorbs more oxygen, assumes a yellow colour, and is then known in com-

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* I stated in the former editions of this work that litharge contained carbonic acid. I found a specimen, from an apothecary in Edinburgh, to contain carbonic acid. But I have since examined about 30 specimens which I selected myself from the different smelting houses in the north of England, and found them all destitute of this acid. There cannot be a doubt therefore that litharge is pure protoxide of lead.

† First Principles, i. 395.

merce by the name of *massicot*. The reason of this change is obvious: the metallic portion of the powder gradually absorbs oxygen, and the whole of course is converted into yellow oxide.

2. If massicot, ground to a fine powder, be put into a furnace, and constantly stirred while the flame of the burning coals plays against its surface, it is, in about 48 hours, converted into a beautiful red powder, known by the name of *minium* or *red lead*.* This powder, which is likewise used as a paint, and for various other purposes, is the *red oxide of lead*.

Red oxide.

Red lead is a tasteless powder, of an intense red colour, often inclining to orange, and very heavy; its specific gravity, according to Harepath, being 9·096. It loses no sensible weight in a heat of 400°; but when heated to redness, it gives out oxygen gas, and gradually runs into a dark brown glass of considerable hardness. By this treatment it loses from four to seven parts in the hundred of its weight, and a part of the lead is reduced to the metallic state. Red lead does not appear to combine with acids. Many acids indeed act upon it, but they reduce it in the first place to the state of yellow oxide.

If we pour distilled vinegar on red lead, and digest it for some time, a portion of protoxide is dissolved, and the red lead loses its scarlet colour and assumes a dark brownish red tinge. We see from this that red lead is a mixture or compound of protoxide and deutoxide of lead. I believe the proportions vary. But, in one experiment, with a very fine specimen, the red lead, after this treatment, was found to have lost nearly half its weight. The dark brown matter that remains is deutoxide of lead. I have shown† by an experiment which I consider as conclusive, that deutoxide of lead thus purified is a compound of

1 atom lead	. .	13
1½ atom oxygen	. .	1·5
		——
		14·5

Its atomic weight is therefore 14·5. So far as is known at present this oxide does not possess the property of uniting either with acids or bases. When heated to redness it gives out oxygen, and is reduced to protoxide. When digested in sulphurous acid sulphate of lead is formed. Nitric acid converts it into protoxide and peroxide.

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* See an account of the method of manufacturing *red lead* in Watson's Chemical Essays, iii. 338.

† First Principles, i. 398.

3. If nitric acid, of the specific gravity 1·260, be poured upon red lead, 185 parts of the oxide are dissolved; but 15 parts remain in the state of a black or rather deep brown pow- der.* This is the *peroxide* or *brown oxide of lead*, first discovered by Scheele. It may be prepared in the following manner, which was pointed out by Proust, and afterwards still farther improved by Vauquelin: Put a quantity of red oxide of lead into a vessel partly filled with water, and make chlorine gas pass into it. The oxide becomes deeper and deeper coloured, and is at last dissolved. Pour potash into the solution, and the brown oxide of lead precipitates. By this process 68 parts of brown oxide may be obtained for every 100 of red oxide employed.†

This oxide is a tasteless powder of a flea-brown colour, and having a specific gravity, according to Harepath, of 8·902. It is not acted on by sulphuric or nitric acids. From muriatic acid it absorbs hydrogen, and converts it into chlorine. When heated it gives out the half of its oxygen and is converted into yellow oxide.‡ Hence it is obvious that the peroxide of lead is a compound of

1 atom lead	.	. .	13
2 atoms oxygen	.	. .	2
			——
			15

4. All the oxides of lead are very easily converted into glass: and in that state they oxidize and combine with almost all the other metals except gold, platinum, silver, and the metals recently discovered in crude platina. This property renders lead exceedingly useful in separating gold and silver from the baser metals with which they happen to be contaminated. The gold or silver to be purified is melted along with lead, and kept for some time in that state in a flat cup, called a *cupel*, made of burnt bones, and the ashes of wood. The lead is gradually vitrified, and sinks into the cupel, carrying along with it all the metals which were mixed with the silver and gold, and leaving these metals in the cupel in a state of purity. This process is called *cupellation*.

III. When lead is introduced into chlorine gas it does not burn; but it absorbs the gas, and is converted into *chloride of lead*. This substance is easily obtained by mixing a solution

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* Scheele, i. 113, and Proust, Ann. de Chim. xxiii. 98.
† Fourcroy, iv. 91.   ‡ Berzelius; Ann. de Chim. lxxviii. 16.

Chap. III. of nitrate of lead with a solution of common salt. A precipitate falls, consisting of small, white, silky crystals. When these crystals are heated they melt, but do not lose any weight, showing that they were in the state of chloride. This compound was formerly distinguished by the name of *plumbum corneum*, or *horn lead*. It is a semi-transparent grayish-white mass, having some resemblance to horn in appearance. When heated in the open air it partly evaporates in a white smoke; but when the access of air is excluded, it remains fixed at a red heat. Dr. John Davy first showed that this chloride is a compound of

1 atom lead	. .	13
1 atom chlorine	. .	4·5
		17·5*

Dichloride.   There is another chloride of lead which may be obtained by digesting the common chloride in a solution of potash. It is a white powder, which was first pointed out by Vauquelin.† It has not been analyzed, but is probably a dichloride, or a compound of

2 atoms lead	. .	26
1 atom chlorine	. .	4·5
		30·5

Turner's yellow.   What is called Turner's, or patent yellow, is probably a mixture of this dichloride and oxide of lead. It is prepared by mixing one part of moistened common salt with about seven parts of litharge. The common salt is decomposed, and soda set free. The residual matter, after washing out the soda, being fused, becomes yellow, and constitutes the pigment in question.

Bromide.   IV. When some drops of a hydrobromate, dissolved in water, are let fall into a solution of lead, a white precipitate falls, having the crystalline appearance of chloride of lead. When strongly heated this matter fuses into a red liquor, which gives out white fumes, and which, on cooling, concretes into a beautiful yellow substance.—This bromide, when in a state of disintegration, is decomposed by nitric and sulphuric acids, bromine being disengaged. But after fusion it is not attacked by nitric acid; though it may be still decomposed by boiling sul-

* Phil. Trans. 1812, p. 185.   † Ann. de Chim. xxxi. 3.

phuric acid. This bromide has not been subjected to analysis, but there can be little doubt that it is a compound of

1 atom bromine	. .	10
1 atom lead	. . .	13
		23*

V. Lead combines readily with iodine when the two sub-stances are heated together. The iodide of lead has a fine yellow colour. It is precipitated whenever a hydriodate is dropped into a solution containing lead. It is insoluble in water. It dissolves in potash ley, and in distilled vinegar, at a boiling temperature, and precipitates when the solution cools in yellow plates. Though this iodide has not been analyzed, there can be no doubt, from analogy, that it consists of *Iodide.

1 atom lead	. . .	13
1 atom iodine	. .	15·75
		28·75

VI. Nothing is known respecting any combinations which lead may be capable of forming with hydrogen, azote, carbon, or boron.

VII. Berzelius found that lead and silicon, when fused together before the blow-pipe, formed an alloy which, when dissolved in nitric acid, left a small quantity of silica behind it.† *Phosphuret.*

VIII. Phosphuret of lead may be formed by mixing together equal parts of filings of lead and phosphoric glass, and then fusing them in a crucible. It may be cut with a knife, but separates into plates when hammered. It is of a silver-white colour with a shade of blue, but it soon tarnishes when exposed to the air. This phosphuret may also be formed by dropping phosphorus into melted lead. It is composed of about 12 parts of phosphorus and 88 of lead.‡ This approaches 1 atom of lead and 1 atom of phosphorus.

IX. There seem to be three combinations of sulphur and lead. *Sulphurets.*

1. Sulphuret of lead may be formed, either by stratifying its two component parts and melting them in a crucible, or by dropping sulphur at intervals on melted lead. The sulphuret of lead is brittle, brilliant, of a deep blue-gray colour, and much less fusible than lead. These two substances are often

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* Balard; Ann. de Chim. et de Phys. xxxii. 359.
† Annals of Philosophy (2d series), x. 120.
‡ Pelletier, Ann. de Chim. xiii. 114.

found naturally combined; the compound is then called *galena*, and is usually crystallized in cubes. The specific gravity varies somewhat, but is not much below 7·6.

It has been established by the most unexceptionable experiments that it is a compound of

1 atom lead	13
1 atom sulphur	2
	15

When exposed to a red heat it partly sublimes in the state of sulphate of lead. If it be mixed with iron and heated, the sulphur unites to the iron and sets the lead at liberty. This method of reducing lead from galena is practised in some parts of the continent. When treated with nitric acid, it may be converted into sulphate of lead. Digestion in concentrated muriatic acid converts it into chloride of lead, while sulphuretted hydrogen gas is evolved.

Disulphuret.   2. Arfvedson found that when a current of dry hydrogen gas is passed over sulphate of lead heated to redness, as long as decomposition goes on, the lead is reduced to the metallic state, while all the oxygen and half the sulphur of the acid is abstracted.* It is obvious that by this process a disulphuret of lead or a compound of

2 atoms lead	26
1 atom sulphur	2
	28

was formed.

Bisulphuret.   3. Besides this common sulphuret of lead there occurs another occasionally, lighter in colour, and less brilliant, which burns in the flame of a candle, or when put upon burning coals, emitting a blue flame. This variety of galena is not uncommon in the north of England. I had an opportunity of analyzing a specimen of the kind of lead ore from Ireland, and found it a compound of

> 12 atoms lead,
> 13 atoms sulphur.

The only simple view that can be taken of such a compound, is to consider it as a mixture of combinations of

> 11 atoms sulphuret of lead,
> 1 atom bisulphuret of lead.

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* Ann. de Chim. et de Phys. xxvii. 184.

And if this view be admitted, it is plain that a bisulphuret of lead must exist, though it has not yet been formed artificially.

X. Lead and selenium readily unite, and heat is evolved during the combination. The lead swells, and forms a porous mass of a gray colour, which does not melt at a red heat; but is soft, easily polished, and then has the whiteness of silver. When heated, it gives out a little selenium, and then sublimes in part in the form of a white smoke.*

XI. Lead and arsenic may be combined by fusion. The alloy is brittle, dark-coloured, and composed of plates. Lead takes up ⅛th of its weight of arsenic.† This corresponds very nearly with

2 atoms lead	. .	26
1 atom arsenic	. .	4·75
		————
		30·75

XII. When equal parts of lead and antimony are fused, the alloy is porous and brittle: 3 parts of lead and 1 of antimony form a compact alloy, malleable, and much harder than lead: 12 parts of lead and 1 of antimony form an alloy very malleable, and a good deal harder than lead: 16 parts of lead and 1 of antimony constitute an alloy of very nearly 10 atoms lead and 1 antimony; 12 lead and 1 antimony is very nearly 7·5 atoms lead and 1 atom antimony; while 3 lead and 1 antimony approach 2 atoms of lead and 1 of antimony.

XIII. Ten parts of lead and one of molybdenum, when melted together, form an alloy which is somewhat malleable, and whiter than pure lead. When kept heated, the lead partly eliquates. When the proportion of molybdenum is increased, the alloy becomes brittle, dark-coloured, and more difficult of fusion.‡

XIV. With 100 lead and 100 tungsten, a button was obtained of a dull dark brown, with very little lustre, spongy, very ductile, and splitting into leaves when hammered; it weighed 127 grains.

XV. Lead may be easily alloyed with potassium. The two metals unite when the heat is raised sufficiently high to fuse the lead. The alloy is very fusible and brittle. Its texture is fine granular. When exposed to the air it is speedily destroyed. It effervesces in water. The potassium is converted into potash, and the lead remains unaltered.§ Serullas formed this alloy by

* Berzelius, Ann. de Chim. et de Phys. x. 245.   † Bergman.
‡ Crell's Annals, iii. 388.
§ Gay-Lussac and Thenard; Recherches Physico-chimiques, i. 218.

exposing to a strong heat for 2 hours in a covered crucible, a mixture of 100 parts litharge and 60 calcined cream of tartar. The alloy is silver white and breaks very easily.*

The alloy of lead and sodium may be formed in the same manner. This alloy has some ductility. It is fine granular, and has a bluish-gray colour, and is nearly as fusible as lead. When exposed to the air, or placed under water, the sodium is speedily converted into soda, and the lead separates unaltered.†

XVI. We do not know the alloys which lead forms with the metallic bases of the alkaline earths and earths proper.

XVII. The older chemists affirm, that iron is not taken up by melted lead at any temperature whatever, but that it constantly swims upon the surface. Muschenbroeck, however, succeeded in uniting by fusion 460 parts of iron with 134 parts of lead, and formed a hard alloy, whose tenacity was not $\frac{1}{2}$ of that of pure iron. The specific gravity of an alloy of 10 iron and 1 lead, according to him, is 4·250.‡ The experiments of Guyton Morveau have proved, that when the two metals are melted together, two distinct alloys are formed. At the bottom is found a button of lead containing a little iron; above is the iron combined with a small portion of lead.§

XVIII. Lead cannot readily be combined with nickel by fusion.

XIX. It was supposed formerly that cobalt does not combine with lead by fusion; for upon melting equal parts of lead and cobalt together, both metals are found separate, the lead at the bottom and the cobalt above. Indeed, when this cobalt is melted with iron, it appears that it had combined with a little lead; for the iron combines with the cobalt, and the lead is separated.‖ But Gmelin has shown that the alloy may be formed. He put cobalt in powder within plates of lead, and covered them with charcoal to exclude the air. He then applied heat to the crucibles containing the mixtures. Equal parts of lead and cobalt produced an alloy, in which the metals appeared pretty uniformly distributed, though in some cases the lead predominated. It was brittle, received a better polish than lead, which metal it resembled rather than cobalt; its specific gravity was 8·12. Two parts of lead and one of cobalt produced an uniform mixture, more like cobalt than lead, very little malleable, and

* Ann. de Mines, viii. 151.
† Gay-Lussac and Thenard; Recherches Physico-chimiques, i. 241.
‡ Wasserberg, i. 212.   § Ann. de Chim. lvii. 47.
‖ Gellert, p. 137.

softer than the last. Its specific gravity was 8·28. Four parts of lead and one of cobalt formed an alloy still brittle, and having the fracture of cobalt, but the polish of lead. It was harder than lead. Six parts of lead and one of cobalt formed an alloy more malleable, and harder than lead. Its specific gravity was 9·65. Eight parts of lead and one of cobalt was still harder than lead, and it received a better polish. It was as malleable as lead. Its specific gravity was 9·78.*

●XX. We do not know the alloys which lead forms with manganese, cerium, and uranium.

XXI. The alloy of lead and zinc has been examined by Wallerius, Gellert, Muschenbroeck, and Gmelin. This last chemist succeeded in forming the alloy by fusion. He put some suet into the mixture, and covered the crucible, in order to prevent the evaporation of the zinc. When the zinc exceeded the lead very much, the alloy was malleable, and much harder than lead. A mixture of two parts of zinc and one of lead formed an alloy more ductile, and harder than the last. A mixture of equal parts of zinc and lead formed an alloy differing little in ductility and colour from lead; but it was harder, and more susceptible of polish, and much more sonorous. When the mixture contained a smaller quantity of zinc, it still approached nearer the ductility and colour of lead, but it continued harder, more sonorous, and susceptible of polish, till the proportions approached to 1 of zinc and 16 of lead, when the alloy differed from the last metal only in being somewhat harder.†

XXII. The alloy of bismuth and lead is brittle; its colour is nearly that of bismuth ;●its texture lamellar; and its specific gravity greater than the mean. According to Muschenbroeck, the specific gravity of an alloy of equal parts bismuth and silver is 10·7097.‡

Zinc.

SECTION IV.—OF TIN.

Tin was known to the ancients in the most remote ages. The Phœnicians procured it from Spain § and from Britain, with which nations they carried on a very lucrative commerce. At how early a period they imported this metal we may easily conceive, if we recollect that it was in common use in the time of Moses.‖

History.

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* Ann. de Chim. xix. 357. † Ibid. ix. 95. ‡ Wasserberg, i. 160.
§ Pliny, lib. iv. cap. 34, and lib. xxxiv. cap. 47. ‖ Numbers xxxi. 22.

Tin is rather a scarce metal, and it occurs in the earth in only two forms; namely that of *peroxide*, usually contaminated with a certain portion of oxides of iron and manganese; and of a *double sulphuret* of tin and copper, which however is a very rare mineral. There are but few spots on the surface of the earth where the ores of tin occur in any considerable quantity. Cornwall has been celebrated for its tin mines from the remotest ages, and it still is the most productive country in Europe. The mountains which separate Galicia from Portugal, were also very productive of tin in ancient times, and still continue unexhausted. The mountains between Saxony and Bohemia, have been wrought as tin mines for several centuries, and still continue productive. These are the only localities of tin ores in Europe. Mines of it occur in the peninsula of Malacca in India, in Chili, and in Mexico; but we are still destitute of a good geological account of the districts where they occur.

The only ore of tin from which the metal is extracted is *tin-stone*, or the peroxide of tin and iron. It occurs in Cornwall in two states. 1. In veins, where it is intimately mixed with a considerable number of other minerals, from which it is difficult to free it. 2. In loose grains or sand in alluvial soil. In this state it goes by the name of *stream-tin*, and it is free from every impurity except nodules of hematite. Hence it is from stream-tin that the purest metal, known by the name of *grain-tin*, is extracted. The *block-tin*, which is less pure, is obtained from the ore dug out of veins.

The first process to which the ore is subjected is *grinding*. The ground ore is then washed, which removes a great deal of impurity. For the specific gravity of tin ore is so high, that it is easy to wash away the earthy matter, and even some of the foreign metallic ores with which it is naturally mixed. But there are other bodies so nearly of the same specific gravity of the tin ore, that they cannot be washed away. The next process is roasting the ore in a reverberatory furnace; this expels the sulphur and arsenic with which the foreign matters were combined, and thus diminishes their specific gravity so much that they can now be washed away.

The tin ore thus freed as much as possible from foreign matter, is mixed with Welch culm and limestone, and heated strongly in a reverberatory furnace so as to bring the whole into the state of fusion, which is kept up for about 8 hours. The lime unites with the earthy matters still mixed with the ore, and flows with them into a liquid glass, while the coal reduces the

oxide of tin to the metallic state. It tumbles by its weight,to the bottom, and is at the end of about 8 hours let out by tapping a hole in the furnace which had been filled with clay.

The tin thus obtained is still very impure. It is put back into the furnace, and exposed to a heat just sufficient to melt it. The pure tin flows out into a kettle, while a quantity of impurity remains behind not melted. The tin in the kettle is kept in fusion and agitated, by which a quantity of impurity accumulates on the surface. It is skimmed off, and the tin now refined is cast into blocks, weighing each about 3 cwt. The stream-tin is smelted by means of charcoal, and the fire is urged by bellows. Hence the place where the process is conducted is called a *blowing-house.* The mass of grain-tin is heated till it become brittle, it is then let fall from a height. By this it splits into a great number of irregular prisms somewhat like basalt pillars. This splitting is a mark of the purity of the tin, for it does not happen when the tin is impure.*

Tin when pure has a fine white colour like silver; and when fresh, its brilliancy is very great. It has a slightly disagreeable taste, and emits a peculiar smell when rubbed. Its hardness is between that of gold and lead. Its specific gravity, according to Harepath, is 7·285.† Brisson states it at 7·291, and informs us that by hammering it may be made as high as 7·299.‡

Properties.

It is very malleable: tin leaf, or *tinfoil* as it is called, is about $\frac{1}{1000}$ part of an inch thick, and it might be beat out into leaves as thin again if such were wanted for the purposes of art. Its ductility and tenacity are much inferior to that of most of the metals known to the ancients. A bar of tin, $\frac{1}{4}$ inch in diameter, is broken by a weight amounting to 296 lbs.§ Hence a tin wire $\frac{1}{10}$th of an inch in diameter would be just broken by a weight amounting to 47·36 lbs. avoirdupois. According to the experiments of Guyton de Morveau, a tin wire 0·078 inch in diameter is capable of supporting a weight of 34·7 pounds only without breaking.‖ Tin is very flexible, and produces a remarkable crackling noise when bended.

* For a more minute detail of the processes followed in Cornwall for smelting tin, the reader is referred to a paper by Mr. John Taylor, Annals of Philosophy (2d series), iii. 449; and to another paper on the subject by M. Bonnard, Jour. des Mines, xiv. 443.

† Phil. Mag. lxiv. 322.

‡ Four specimens of Malacca tin gave the following specific gravities; 7·26; 7·29; 7·27; 7·26.

§ Rennie, Phil. Trans. 1818, p. 126.

‖ Morveau, Ann. de Chim. lxxi. 223.

When heated to the temperature of 442°* it melts; but a very violent heat is necessary to cause it to evaporate. When cooled slowly, it may be obtained crystallized in the form of a rhomboidal prism.†

Oxides.

II. When exposed to the air it very soon loses its lustre, and assumes a grayish-black colour, but undergoes no farther change; neither is it sensibly altered by being kept under cold water; but when the steam of water is made to pass over red-hot tin, it is decomposed, the tin is oxidated, and hydrogen gas is evolved.‡

When tin is melted in an open vessel, its surface becomes very soon covered with a gray powder, which is an oxide of the metal. If the heat be continued, the colour of the powder gradually changes, and at last it becomes yellow. When tin is heated very violently in an open vessel it takes fire, and is converted into a white oxide, which may be obtained in crystals.

The first correct experiments on the oxides of tin were made by Proust.§ The subject was afterwards investigated by Dr. John Davy, ‖ Berzelius,¶ and Gay-Lussac.** It forms two oxides. The *protoxide* has a *black* colour; but when combined with water is *white*. The peroxide is *yellow*, and in certain circumstances *transparent*, and nearly *white*.

1. Protoxide.

1. The *black oxide* or *protoxide* may be obtained by the following process: Dissolve tin in muriatic acid till a saturated solution is obtained. Precipitate the liquid by means of carbonate of soda. Collect the precipitate on a filter and wash it well, then press it between folds of filtering paper, and dry it in a temperature not exceeding 180°. By this process a white powder is obtained, which is a hydrated protoxide, and contains no carbonic acid. Put it into a small retort, which must be filled with hydrogen or carbonic acid gas, and the receiver had better be filled with the same gas. Then raise the retort gradually to an incipient red heat, the water will be driven off, and the protoxide of tin remains behind in a state of purity. It is a black powder, without much lustre, tasteless, and insoluble in water. It may be kept in a dry place without undergoing alteration;

* Crichton, Phil. Mag. xv. 147. This experiment was repeated by Mr. Crichton, jun. with the same result.

† Pajot, jour. de Phys. xxxviii. 52.

‡ Bouillon La Grange, Ann. de Chim. xxxv. 208. Gay-Lussac, Ibid. lxxx. 170.

§ Ann. de Chim. xxviii. 213. ‖ Phil. Trans. 1812, p. 194.

¶ Nicholson's Journal, xxxv. 122. ** Ann. de Chim. lxxx. 170.

but in a moist atmosphere it gradually absorbs oxygen, and is
converted into peroxide. When heated in the open air it takes fire, burns brilliantly, and is converted into peroxide. Even the hydrated protoxide gives some symptoms of burning when thus treated, though the combustion is far inferior to that of the anhydrous protoxide. It dissolves in acids without effervescence, and the hydrate is more easily soluble than the anhydrous oxide. It dissolves also in the fixed alkaline leys. It is distinguished from the peroxide of tin, not only by its colour, but by being *insoluble* in caustic ammonia and in carbonate of potash, in both of which the peroxide dissolves.

According to Berzelius's experiments, this oxide is a compound of

$$\text{Tin} \quad 100 \quad \text{or } 7\cdot35$$
$$\text{Oygen} \quad 13\cdot6 \quad \text{or } 1$$

I have shewn by an experiment which I consider as decisive, that it is a compound of

1 atom tin	. .	7·25
1 atom oxygen	. .	1
		————
		8·25*

Hence the atomic weight of tin must be 7·25.

2. The peroxide of tin exists abundantly native, though most commonly not free from admixture of iron. When pure its colour is yellow; it is translucent or almost transparent; it is crystallized in octahedrons, having a square base, or in modifications from that form. Its specific gravity is about 6·6, and it is fully as hard as felspar. It is quite insoluble in all acids, till it has been fused with an alkali. It may be obtained artificially by raising tin to a white heat in the open air, it takes fire and is converted into peroxide. When the oxide was formed in this way, it used formerly to be called *flowers of tin.*

It may be obtained also by treating tin with moderately concentrated nitric acid. A violent effervescence ensues, and the whole of the tin is converted into a white powder, which is deposited at the bottom of the vessel. When heated so as to drive off all the acid and water, it assumes a yellow colour. When tin filings and red oxide of mercury are heated together, the peroxide of tin is obtained of a white colour; but in every other respect it possesses the properties of common peroxide of tin.† This oxide does not dissolve in muriatic acid, but it forms

* Annals of Philosophy (2d series), ii. 123.
† Berzelius, Nicholson's Journal, xxxv. 130.

a combination with it which is soluble in water. In the same way when digested with potash it combines with that alkali, and the compound dissolves in water. When this solution is evaporated it leaves a yellow jelly, again soluble in water. It appears also to combine with sulphuric acid though the compound does not dissolve in water, because that liquid unites in preference with the acid. When this oxide is exposed to a red heat it is no longer dissolved by acids or water. The same property is observable in most metallic oxides. Thus the peroxide of tin is capable both of acting the part of an acid and of a salifiable base. But the union which it forms both with acids and bases is very weak, since heat alone is sufficient to separate it again.

When this acid is formed by digesting tin in nitric acid, if the white produce be digested in water till all traces of nitric acid be removed, and then dried by a heat of about 132°, it constitutes a white matter, which is a hydrate composed of

1 atom peroxide	. .	9·25
1 atom water	. .	1·125
		10·375

according to the experiments of Berzelius. In this state it reddens vegetable blues. But after the water has been driven off it does not possess that property. I find that if it be dried in a temperature not higher than 55° or 60° it has a silky lustre, and contains twice as much water. For it is in that case a compound of

1 atom peroxide	. .	9·25
2 atoms water	. .	2·25
		11·5

This peroxide is soluble in the caustic alkalies, and also in the alkaline carbonates; which enables us easily to separate it from the protoxide.

When the peroxide of tin is obtained by adding an alkali to the aqueous solution of bichloride of tin, it possesses several properties which distinguish it from the peroxide prepared by means of nitric acid. It is soluble in dilute nitric acid, sulphuric acid, and muriatic acid, whereas the oxide by nitric acid is not soluble in any of these acids. Doubtless these differences depend upon the state of aggregation of the oxide.

I have shown by an experiment which appears to me decisive that peroxide of tin is a compound of

| 1 atom tin | . | . | 7·25 |
| 2 atoms oxygen | . | . | 2 |

9·25*

Berzelius makes the atomic weight of tin 7·35. The experiments of Dr. John Davy give 7·235 for the atomic weight, and with these the analysis of Klaproth corresponds.

III. Dr. John Davy has shown that tin combines with two *Chlorides.* proportions of chlorine, and forms two *chlorides*, which he has examined and analyzed.

1. Protochloride of tin may be formed by heating together *1. Protochloride.* an amalgam of tin and calomel, or by evaporating to dryness the protomuriate of tin and fusing the residue in a close vessel. It has a gray colour, a resinous lustre and fracture and takes fire when heated in chlorine gas, and is converted into perchloride of tin. In close vessels it may be fused at a heat rather below redness without decomposition; but when strongly heated it seems to be partially decomposed. Water dissolves it.

From Dr. John Davy's analysis, who found it a compound of 100 tin and 60·71 chlorine, it is obvious that it consists of

| 1 atom tin | . | . | 7·25 |
| 1 atom chlorine | . | . | 4·5 |

11·75

It appears from the experiments of Proust, confirmed by those of Dr. Davy, that when a little alkali is mixed with a solution of chloride of tin a white powder falls, which is a dichloride or compound of

| 2 atoms tin | . | . | . | 14·5 |
| 1 atom chlorine | . | . | 4·5 |

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When heated to redness chloride of tin sublimes, and a quantity of protoxide of tin remains.

2. The perchloride of tin has been long known under the *Perchloride.* name of *fuming liquor of Libavius*, because it was discovered by Libavius, a chemist of the 16th century. It is usually prepared by mixing together an amalgam of tin and corrosive sublimate, and distilling with a very moderate heat. The proportions that answer best, according to Sulze, are 6 parts of tin, 1 part of mercury, and 33 parts of corrosive sublimate.† The

* Annals of Philosophy (2d series), ii. 123.
† Gehlen's Journal, iv. 438.

distillation is to be conducted with a very moderate heat. At first a colourless liquid passes into the receiver, consisting chiefly of water: then the fuming liquor rushes all at once into the receiver in the state of a white vapour. John Davy found that the perchloride of tin may be prepared, likewise, by mixing a concentrated permuriate of tin with sulphuric acid, and distilling with a gentle heat. It is formed, likewise, when tin is introduced into chlorine gas. The metal catches fire and perchloride sublimes.

Fuming liquor of Libavius is a colourless liquid like water and very fluid. When exposed to the air it smokes with great violence, owing, as Adet first showed, to its avidity for moisture. When 1 part of water and 3 parts of fuming muriate are mixed together, the mixture condenses into a solid mass. Hence the reason that crystals appear on the surface of this liquor, when kept in a phial, with a common cork stopper. It gradually imbibes moisture from the air and crystallizes in consequence. These crystals fall to the bottom of the liquor and remain unaltered. Dr. Davy found that this liquor acts with great violence on oil of turpentine. In one case, indeed, it set the oil on fire. According to his experiments, perchloride of tin is composed of

Tin	. .	100
Chlorine	. .	140·44*

I made two analyses of it, which did not exactly correspond; but the mean did not differ much from the result obtained by Dr. Davy. It is obvious from this that fuming liquor of Libavius generally contains an excess of chlorine. It ought to be a compound of

1 atom tin	. .	7·25
2 atoms chlorine	. .	9
		———
		16·25

Now this is equivalent to

Tin	. . . .	100
Chlorine	. . .	124

It appears from this that the excess of chlorine in this chloride amounts to about ¼th of an atom.

Bromide.

IV. Balard has shown that tin and bromine unite in two proportions.

1. Protobromide.

1. Protobromide is obtained by dissolving tin in hydrobro-

mic acid, and evaporating the solution to dryness. It is com-posed of

1 atom bromine	.	.	10
1 atom tin	.	.	7·25
			17·25

2. The bibromide of tin may be formed by bringing tin in contact with bromine. It catches fire and is converted into a white solid body of a crystalline texture, easily fusible and volatile. It gives out only traces of vapours, dissolves in water without the evolution of heat, and forms a bibromate of tin. Put into hot sulphuric acid it liquefies and remains at the bottom like oil. Nitric acid disengages bromine from it instantly. It is composed of

2 atoms bromine	.	.	20
1 atom tin	.	.	7·25
			27·25*

V. Iodine combines readily with tin when the melted metal is brought in contact with the vapour of this supporter. The iodide has a dirty orange colour, and is very fusible. Water decomposes it completely, converting it into hydriodic acid and oxide of tin. When tin and iodine are heated together under water, they act upon each other, and are converted respectively into hydriodic acid and oxide of tin.[†] This iodide has not been analyzed, but from the change which it undergoes when put into water, there can be no doubt that it is a compound of

1 atom tin	.	.	7·25
1 atom iodine	.	.	15·75
			23

VI. Professor Kastner affirms that when tin is dissolved in moderately strong muriatic acid, the hydrogen gas extricated contains tin in combination, and that it constitutes *stannetted hydrogen.* It has a peculiar and penetrating odour, and when compressed into water is dissolved in considerable quantity. It burns with a blue light, and gives off white fumes of oxide of tin. When passed into a dilute solution of gold, powder of Cassius is immediately formed. On this account he recommends it as a test of the presence of minute portions of gold.[‡]

* Balard, Ann. de Chim. et de Phys. xxxii. 359.
† Gay-Lussac, Ann. de Chim. xci. 26.
‡ Annals of Philosophy (2d series), iv. 156.

The only one of these phenomena that I have observed is the peculiar smell of the hydrogen gas evolved.   It is strong and very unpleasant, and has been hitherto ascribed to arsenic.

VII. No combination of tin with azote, carbon, or boron, is at present known.

VIII. When fused with silicon a combination takes place, according to Berzelius, who, however, has not given any description of the compound.   When dissolved in acids it leaves behind it a considerable portion of silica.*

IX. Phosphuret of tin may be formed by melting, in a crucible, equal parts of filings of tin and phosphoric glass.   Tin has a greater affinity for oxygen than phosphorus has.   Part of the metal, therefore, combines with the oxygen of the glass during the fusion, and flies off in the state of an oxide, and the rest of the tin combines with the phosphorus. The phosphuret of tin may be cut with a knife; it extends under the hammer, but separates in laminæ.   When newly cut, it has the colour of silver; its filings resemble those of lead.   When these filings are thrown on burning coals, the phosphorus takes fire. This phosphuret may likewise be formed by dropping phosphorus gradually into melted tin.   According to Pelletier, to whose experiments we are indebted for the knowledge of all the phosphurets, it is composed of about 85 parts of tin and 15 of phosphorus.†   This corresponds very nearly to

$1\frac{1}{2}$ atom tin   .   .   11·25
1   atom phosphorus   .   2
                                  ————
                                  13·25

X. Tin combines, in three proportions, with sulphur, and forms three different sulphurets.

1. The sulphuret of tin may be formed by fusing tin and sulphur together, reducing the compound formed to powder, mixing it with sulphur, fusing it a second time, and keeping the temperature sufficiently high to volatilize the superfluous sulphur.   It has the colour of lead, the metallic lustre, and is capable of crystallizing.   When dissolved in concentrated muriatic acid it is totally converted into protoxide of tin and sulphuretted hydrogen gas.   Hence it is obviously a compound of

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* Annals of Philosophy (2d series), x. 120.
† Ann. de Chim. xiii. 116.

1 atom tin	.	. .	7·25
1 atom sulphur		. .	2
			9·25

L. Gmelin says that its specific gravity is greater than that of tin. It is much more difficult of fusion than tin.

2. When sulphuret of tin, reduced to powder, is mixed with the third part of its weight of sulphur, and exposed in a retort to a dull red heat, it combines with an additional dose of sulphur, and a compound is formed, consisting, according to Berzelius, of

Sesquisulphuret.

1 atom tin	.	. .	7.25
1½ atom sulphur		. .	3
			10·25

This sesquisulphuret has a dark yellowish gray colour, the metallic lustre, and when rubbed, acquires considerable brilliancy. When digested in muriatic acid, sulphuretted hydrogen gas is given out, and a yellow matter is left behind. By this process one half of the tin is dissolved, and the other half converted into persulphuret of tin.*

3. Persulphuret of tin has been long known in chemistry under the name of *aurum mosaicum* or *musivum, mosaic gold.* I do not know when it was discovered, but Kunkel gives a formula for preparing it. In the year 1771 Mr. Woulfe rectified the old process, and proposed the following method of making this substance, which is much cheaper than the old one. Mix together 12 parts tin, 7 parts sulphur, 3 parts mercury, and 3 parts sal ammoniac. Expose the mixture to a strong heat for eight hours in a black lead crucible, to the top of which an aludel is luted. The mosaic gold sublimes.† In the year 1792 Pelletier published a set of experiments on this compound, and showed that it might be prepared by heating together, in a retort, a mixture of equal parts of sulphur and oxide of tin. Sulphurous acid and sulphur are disengaged, and mosaic gold remains.‡ Before the appearance of this dissertation it had been the general opinion of chemists that mosaic gold is a compound of tin and sulphur. But Pelletier endeavoured to show that the tin was in the state of an oxide. Proust

Persulphuret.

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* I entertain some doubts respecting the existence of this sesquisulphuret.

† Phil. Trans. 1771, p. 114.   ‡ Ann. de Chim. xiii. 280.

published a valuable set of experiments on it in 1805 in his paper on tin.* According to him it is a combination of sulphur and an oxide of tin, containing less oxygen than the protoxide above described. This opinion was rectified in 1812 by Dr. John Davy, who demonstrated that this substance is a compound of tin and sulphur,† and thus restored the old chemical theory. Berzelius has also examined this compound, and has come to a similar conclusion.‡ Hence there can be no doubt that it is really a sulphuret of tin.

Mosaic gold when pure is in the form of light scales which readily adhere to other bodies, and which have the colour of gold. When heated it gives out a portion of sulphur, and is converted into common sulphuret of tin. It is insoluble in water and alcohol, and is not acted upon either by muriatic or nitric acids. But when nitromuriatic acid is boiled on it we gradually decompose and dissolve it. Potash ley dissolves it when assisted by heat. The solution has a green colour. When an acid is poured into the solution a yellow powder is precipitated, which, according to Proust, is a hydrosulphuret of tin.

There can be no doubt, from the analysis of Dr. Davy, that this sulphuret is a compound of

1 atom tin	.	.	.	7·25
2 atoms sulphur	.	.	4

$$11·25$$

For this is equivalent to

Tin	.	.	100
Sulphur	.	.	55·03

Now Dr. Davy obtained, by analysis,

Tin	.	.	100
Sulphur	.	.	56·25

Seleniet. XI. Selenium and tin unite with the disengagement of heat. The tin swells, but does not become liquid. The mass is gray, and has a very strong metallic lustre when polished. When heated it lets go the selenium much more easily than any other seleniet. The compound does not melt; but the tin remains in the state of an oxide.§

Arseniet. XII. Tin and arsenic may be alloyed by fusion. The alloy is white, harder, and more sonorous than tin, and brittle, unless the proportion of arsenic be very small. An alloy, composed

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* Nicholson's Journal, xiv. 42. † Phil. Trans. 1812, p. 199.
‡ Nicholson's Journal, xxxv. 165.
§ Berzelius, Ann. de Chim. et de Phys. x. 244.

of 15 parts of tin and one of arsenic, crystallizes in large plates like bismuth; it is more brittle than zinc, and more infusible than tin. The arsenic may be separated by long exposure of the alloy to heat in the open air.[*]

XIII. Tin and antimony may be united together in various Antimoniet. proportions. An alloy of 1 atom tin and 1 atom antimony is very brittle and easily pulverized. Its specific gravity is 6·803.[†]

1 part of antimony with 1½ of tin (nearly 1 atom antimony and 1½ atom tin) is brittle and less foliated in its texture than antimony.[‡] 1 part antimony and 3 parts tin form an alloy less ductile than tin, and having a specific gravity of 7·059.[§] One part of antimony and ten parts of tin form a very ductile alloy. The addition of a little lead renders these ductile alloys brittle. Boiling muriatic acid dissolves out all the tin, even from the alloy containing nine-tenths of that metal, and the antimony is left behind as a black powder.

XIV. Equal parts of tin and molybdenum melted into a Alloys with molybdenum. blackish-gray, granular, brittle, soft mass. When 2 parts of tin and 1 of molybdenum were melted together, the alloy was harder than the preceding, but in other respects agreed with it. Four parts of tin and one of molybdenum formed a still harder alloy, which admitted of being hammered a little, did not crackle like tin when bent, and in its fracture exhibited a grayish colour and granular texture. When strongly heated, the tin did not eliquate till the alloy was pressed with the forceps.[||]

XV. When 100 parts of tin and 50 parts of tungstic acid, Tungsten. with some charcoal, are heated together, a brown coloured button is obtained, very spongy, somewhat ductile, and weighing 138 grains.[¶]

XVI. Tin and potassium are easily alloyed by heating them Potassium. together. A weak light is emitted at the instant of combination. The alloy is brittle, not so white as tin, and pretty fusible. It is speedily destroyed either in the air or under water by the conversion of the potassium into potash.[**]

During the combination of sodium and tin no light is disen- Sodium. gaged. This alloy possesses similar properties as the alloy of tin and potassium, but it is less fusible than tin.[††] Serullas has

* Bayen.   † Chaudet.   ‡ Gehlen.
§ Chaudet, Ann. de Chim. et de Phys. iii. 376.
|| Crell's Annals, iii. p. 373.   ¶ Elhuyarts.
** Gay-Lussac and Thenard, Recherches Physico-chimiques, i. 220.
†† Ibid. p. 240.

shown that the first of these alloys may be formed by heating a mixture of 100 parts of oxide of tin, 60 of calcined cream of tartar, and 8 of lamp black.*

Iron.   . XVII. Tin does not combine readily with iron.   An alloy, however, may be formed, by fusing them in a close crucible, completely covered from the external air.   We are indebted to Bergman for the most precise experiments on this alloy. When the two metals were fused together, he always obtained two distinct alloys: the first, composed of 21 parts of tin and 1 part of iron; the second, of 2 parts of iron and 1 part of tin. The first was very malleable, harder than tin, and not so brilliant; the second but moderately malleable, and too hard to yield to the knife.†

Tinplate.   The formation of *tin plate* is a sufficient proof of the affinity between these two metals.   This very useful alloy, known in Scotland by the name of *white iron*, is formed by dipping into melted tin thin plates of iron, thoroughly cleaned by rubbing them with sand, and then steeping them 24 hours in water acidulated by bran or sulphuric acid.   The tin not only covers the surface of the iron, but penetrates it completely, and gives the whole a white colour.‡

XVIII. The alloy of tin and cobalt is of a light violet colour, and formed of small grains.

XIX. Tin and zinc may be easily combined by fusion.   The alloy is much harder than zinc, much stronger than tin, and still ductile.   This alloy, it is said, is often the principal ingredient in the compound called *pewter*.

XX. Bismuth and tin unite readily.   A small portion of bismuth increases the brightness, hardness, and sonorousness of tin : it often enters into the composition of *pewter*, though never in Britain.   Equal parts of tin and bismuth form an alloy that melts at 280° : eight parts of tin and one of bismuth melt at 390° : two parts of tin and one of bismuth at 330°.§

XXI. When eight parts of bismuth, five of lead, and three of tin, are melted together, a white coloured alloy is obtained, which melts at the temperature of 212°, and therefore remains melted under boiling water.

Lead.   XXII. Lead and tin may be combined in any proportion by

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* Ann. de Mines, viii. 151.   † Bergman, iii. 471.
‡ See Watson's Chem. Essays, iv. 191. For an interesting account of this manufactory, by Mr. Parkes, the reader is referred to the Manchester Memoirs, vol. iii. p. 347, second series.
§ Dr. Lewis, Newman's Chem. p. 111.

fusion. This alloy is harder, and possesses much more tena-
city than tin. Muschenbroeck informs us that these qualities
are a maximum when the alloy is composed of three parts of
tin and one of lead. The presence of the tin seems to prevent
in a great measure the noxious qualities of the lead from becom-
ing sensible when food is dressed in vessels of this mixture.

This mixture is often employed to tin copper vessels, and the
noxious nature of lead having raised a suspicion, that such ves-
sels when employed to dress acid food, might prove injurious
to the health, Mr. Proust was employed by the Spanish govern-
ment to examine the subject. The result of his experiments
was, that vinegar and lemon juice, when boiled long in such
vessels, dissolve a small portion of tin, but no lead, the presence
of the former metal uniformly preventing the latter from being
acted on. The vessels of course are innocent.* The specific
gravity of this alloy increases with the lead, as might be
expected. Hence the proportion of the two metals in such
alloys may be estimated nearly from the specific gravity, as
will appear from the following table, drawn up by Dr. Watson
from his own experiments.†

Tin.	Lead.	Sp. grav.
0	100	11·270
100	0	7·170
32	1	7·321
16	1	7·438
8	1	7·560
5	1	7·645
3	1	7·940
2	1	8·160
1	1	8·817

What is called in this country *ley pewter* is often scarcely any Pewter.
thing else than this alloy.‡ *Tinfoil*, too, almost always is a
compound of tin and lead. This alloy, in the proportion of
two parts of lead and one of tin, is more soluble than either of
the metals separately. It is accordingly used by plumbers as
a solder.

* Ann. de Chim. lvii. 73.　　　† Chemical Essays, iv. 165.

‡ There are three kinds of *pewter* in common use; namely, *plate, trifle,*
and *ley*. The plate pewter is used for plates and dishes; the trifle chiefly
for pints and quarts; and the ley metal for wine measures, &c. Their rela-
tive specific gravities are as follows: Plate, 7·248; trifle, 7·359; ley 7·963.
The best pewter is said to consist of 100 tin and 17 antimony. See Watson's
Chemical Essays, iv. 167.

SECTION V.—OF COPPER.

' If we except gold and silver, copper seems to have been more early known than any other metal. In the first ages of the world, before the method of working iron was discovered, copper was the principal ingredient in all domestic utensils and instruments of war. Even during the Trojan war, as we learn from Homer, the combatants had no other armour but what was made of bronze, which is a mixture of *copper* and *tin*. The word *copper* is derived from the island of Cyprus, where it was first discovered, or at least wrought to any extent, by the Greeks. It is obvious, from a passage in the book of Job, which is certainly the oldest of the writings in the Old Testament, since there are strong reasons for believing that existed before Moses, and that it is referred to in more than one passage contained in the five books usually ascribed to that ancient lawgiver, that the method of smelting copper was known and practised at that early age.*

Copper exists rather abundantly in different parts of the earth, and it is found in a great variety of states; the species of copper ores that have been described by mineralogists amounting to 29. But by far the most abundant ores of copper, and those from which almost all the copper of commerce is extracted, are *copper pyrites* and *gray copper* ore. Both of these are sulphur salts, the former being a compound of

$$\begin{cases} \text{1 atom sulphide of copper,} \\ \text{1 atom sulphuret of iron,} \end{cases}$$

the latter of

$$\begin{cases} \text{1 atom sulphide of antimony, or arsenic,} \\ \text{2 atoms sulphuret of copper, or silver.} \end{cases}$$

The richest copper mines are situated in Cornwall, where they occur in veins traversing primary rocks, and consisting chiefly of copper pyrites and gray copper ore. These ores, after being dug out and cleaned, as much as possible, are still mixed with a great quantity of quartzy matter, which accompanied them in the vein, and from which it is impossible, nor would it be desirable, to free them.

The copper ores of Cornwall are mostly transported to Swansea to be smelted, on account of the abundance of coal in that neighbourhood. The processes are numerous; but the theory

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* " Iron is taken out of the earth, and brass (copper) is molten out of the stone," Job xxviii. 2.

of the whole may be reduced to the driving off the sulphur, oxidizing the iron, and converting it into silicate, which separates in the state of scoriæ, while the oxide of copper is reduced to the metallic state. The first process is to roast the ore in a reverberatory furnace, for about 12 hours, occasionally stirring it to expose new surfaces to the air, and taking care not to raise the heat high enough to produce fusion. By this process a great deal of sulphur is driven off, the iron is partly oxidized, and this gives the whole of the ore a black colour. The ore thus roasted is, in the next place, fused in a melting furnace. When in a state of complete fusion it is well stirred, in order to induce as complete a separation as possible of the metal from the slag. By this fusion the silica is made to unite with the protoxide of iron and forms bisilicate of iron, which constitutes the slag. This slag is skimmed off, and then a new charge is poured in and fused as before. And this process is continued till the metallic portion collected in the furnace is as high as the furnace will admit of without running out by the door. A hole is then opened, through which the metal runs out into an adjoining pit filled with water. It thus becomes granulated, and collects in a pan, at the bottom of the cistern, which is raised by means of a crane.

The ore, as originally brought to the smelting-house, contains only, at an average, about $8\frac{1}{2}$ per cent. of copper; but, by the roasting and smelting, so much of the foreign matter is removed that the matter run into the water now contains about one-third of its weight of copper. The success of the process depends upon the proportion existing in the ore between the iron and the quartz. It is often necessary to add either the one or the other of these substances according to the state of the ore. The produce of this first fusion is called, in the smelting-houses, *coarse metal.*

The coarse metal is subjected to another roasting process in a reverberatory furnace, which is continued for 24 hours, and the chief object of which is to oxidize the iron and dissipate the sulphur which may still exist in it. The heat during the first six hours is moderate, and it is gradually increased afterwards to the end of the operation.

The coarse metal thus roasted is fused a second time, being mixed partly with slag (bisilicate of iron) partly with furnace bottoms, &c.; sometimes also it is found requisite to throw in a portion of uncalcined or raw ore. It is supposed that the sul-

phur extricated during this process reduces the copper to the metallic state, but how far this is the case is rather doubtful. The slag obtained consists of *silicate of iron.* It is chiefly to supply the requisite quantity of silica that the additions made during the smelting are useful. The copper ore, by this second smelting, is reduced to a matter containing 60 per cent. of copper. It is either run into water or into sand moulds according to the mode of treatment it is to be subjected to. When run into water it is in grains, and called *fine metal;* when cast in sand it is called *blue metal,* from the colour of its surface.

The calcination, or roasting, is again repeated, and the roasted fine metal is smelted anew. The matter obtained by this third smelting contains about 90 per cent. of pure copper. It is called *coarse copper.*

The coarse copper masses from the last process are filled into the furnace, and exposed to the action of the air which passes through the furnace, at a high temperature. The heat is gradually raised to the melting point, and the expulsion of the volatile matter that remained is thus completed, while the iron, &c. is oxidized. The process lasts from 12 to 24 hours, according to circumstances. The pigs are covered with blisters, and the copper in this state is known by the name of *blistered copper.*

The last process is called the *refining* or *toughening* process. The metal is put into a furnace and exposed at first to a moderate heat, in order to complete the roasting and oxidizing, should that be necessary. The whole is then melted; its surface is covered with charcoal, and a birch pole is plunged into the melted mass. Gas is evolved from this pole, which occasions a kind of boiling. This is repeated till the metal becomes ductile, and acquires the requisite toughness and closeness of grain. It is conceived that the effect produced by this process is the reduction of all the oxide of copper to the metallic state. If the process of *poling* be continued too long, the copper acquires a yellowish red colour and a fibrous texture, and it becomes more brittle than it was at first. It is supposed that this change is owing to a combination of carbon with the copper; but I think that the evidence adduced in favour of this opinion is defective. It appears from the observations of Stromeyer and Hausmann, that a peculiar kind of scales make their appearance in some cases in copper. These scales, from the analysis of Stromeyer, were composed of

Suboxide of copper	.	.	50·50
Protoxide of antimony	.	.	37·05
Protoxide of lead	.	.	4.05
Oxide of silver	.	.	0·16
Oxide of iron	.	.	0·07
Sulphur	.	.	0·80
Silica and alumina	.	.	1·58
			94·21*

The copper containing these scales is brittle, and possesses all the bad qualities of over-poled copper. It is obvious that if the process of poling were continued long enough in such copper, the oxides of which these scales are composed would be reduced, but they would render the copper brittle, and bring it exactly into the state of over-poled copper. How far the over-poled copper from the Cornish ores owes its bad qualities to the presence of foreign metals, remains to be determined. But as gray copper ore and tennantite occurs in Cornwall, it is obvious that both antimony and arsenic must exist in these ores.

There is reason to believe that the copper smelted by the process just described, is seldom or never free from oxide of copper. To this cause I ascribe the short time that it generally lasts when used for sheathing ships. It accounts also for its low specific gravity when compared to that of pure copper. The late Mr. Mushet of the Mint took out a patent for a method of rendering copper much fitter for sheathing ships than it usually is. This method was to fuse the copper, and then add to it about $\frac{1}{300}$th part of its weight of zinc. The copper thus treated was then rolled out into sheets. Its specific gravity and tenacity were very materially increased by this process. Upon analyzing it no trace of zinc could be discovered. But it was evident from the result of the analysis that the whole copper was in the metallic state. I conclude from this that when the zinc was thrown into the melted copper, it had instantly absorbed the oxygen from a portion of oxide of copper contained in the liquid mass. By this absorption the zinc would be oxidized and thrown off, so that not a particle of it would remain united to the copper, except when it was added in greater quantity than was necessary to reduce the oxide of copper. Mr. Mushet's process then, I conceive, improved the copper merely by reducing the whole copper to the metallic state, though a portion of it existed before in the state of oxide.

* Ann. de Chim. et de Phys. xxxiii. 328.

I. Copper has a fine red colour, and a great deal of brilliancy. Its taste is styptic and nauseous; and the hands, when rubbed for some time on it, acquire a peculiar and disagreeable odour. It is harder than silver. Its specific gravity varies according to its state. Lewis found the specific gravity of the finest copper he could procure 8·830.[*] Mr. Hatchett found the finest granulated Swedish copper 8·895.[†] It is probable that the specimens which have been found of inferior gravity were not quite pure.[‡] Cronstedt states the specific gravity of Japan copper at 9·000.[§] Mr. Harepath states the specific gravity of copper at 8·900.[||] I found the specific gravity of Mushet's patent rolled copper 8·953 at 60°, and this is what I am disposed to consider as the true specific gravity of pure copper.

¶ Its malleability is great: it may be hammered out into leaves so thin as to be blown about by the slightest breeze. Its ductility is also considerable. Its tenacity is such, according to Count Sickengen, that a copper wire 0·078 inch in diameter is capable of supporting 302·26 lbs. avoirdupois without breaking.[¶] Mr. Rennie found that a bar of cast copper $\frac{1}{4}$ inch in diameter was broken by a weight of 1192 lbs.; while a bar of wrought copper reduced by the hammer required 2112 lbs. to break it.[**] According to these experiments, a wire of cast copper of $\frac{1}{10}$th inch in diameter is broken by a weight of 190·7 lbs. while a wire of wrought copper of the same diameter requires to break it a weight of 337·9 lbs. avoirdupois.

When heated to the temperature of 27° Wedgewood, or, according to Daniel, 2548° Fahrenheit, it melts; and if the heat be increased, it evaporates in visible fumes. While in fusion it appears on the surface of a bluish green, nearly like that of

* Neuman's Chemistry, p. 61. Fahrenheit had found it 8·834. Phil. Trans. 1714, vol. xxxiii. p. 124.

† On the Alloys of Gold, p. 50. It would have been heavier had it been hammered or rolled. Bergman states the specific gravity of Swedish copper at 9·3243. Opusc. ii. 263.

‡ The following are the results of Mr. Hatchett's trials:

Finest granulated Swedish copper	.	.	8·895
Do. Swedish dollar	.	.	8·799
Do. sheet British do.	.	.	8·785
Fine granulated British do.	.	.	8·607

§ I have had an opportunity of taking the specific gravity of Chinese copper, and found it the same as European. Hence I am inclined to suspect that Cronstedt's number is inaccurate. Indeed I have lately taken the specific gravity of Japan copper, and found it only 8·434.

|| Phil. Mag. lxiv. 322.   ¶ Sickengen, Ann. de Chim. xxv. 9.
** Phil. Trans. 1818, p. 126.

melted gold.* When allowed to cool slowly, it assumes a crys-
talline form. The Abbé Mongez, to whom we owe many valu-
able experiments on the crystallization of metals, obtained it in
quadrangular pyramids, often inserted into one another.

II. Copper is not altered by water : it is incapable of decom-
posing it even at a red heat, unless air have free access to it at
the same time ; in that case the surface of the metal becomes
oxidized. Every one must have remarked, that when water is
kept in a copper vessel, a green crust of *verdigris*, as it is called,
is formed on that part of the vessel which is in contact with the
surface of the water.

When copper is exposed to the air, its surface is gradually
tarnished; it becomes brown, and is at last covered with a dark
green crust. This crust consists of oxide of copper combined
with carbonic acid gas. At the common temperature of the air,
this oxidizement of copper goes on but slowly ; but when a plate
of metal is heated red hot, it is covered in a few minutes with
a crust of oxide, which separates spontaneously in small scales
when the plate is allowed to cool. The copper plate contracts
considerably on cooling, but the crust of oxide contracts but
very little ; it is therefore broken to pieces and thrown off, when
the plate contracts under it. Any quantity of this oxide may
be obtained by heating a plate of copper and plunging it alter-
nately in cold water. The scales fall down to the bottom of
the water. When copper is kept heated below redness, its sur-
face gradually assumes beautifully variegated shades of orange,
yellow, and blue. Thin plates of it are used in this state to
ornament children's toys. In a violent heat, or when copper
is exposed to a stream of oxygen and hydrogen gas, the metal
takes fire and burns with some brilliancy, emitting a lively
green light. The product is an oxide of copper.

Three combinations of copper and oxygen have been described
by chemists. There is one which exists native, having a dark
red colour and crystallized in octahedrons, and which contains
the smallest quantity of copper. It may be called the *suboxide*.
There is another which may be formed by exposing copper
filings for a long time to a red heat, which has a black colour,
and constitutes the basis of the cupreous salts. It may be called
oxide of copper. There is a third oxide formed by Thenard by
means of deutoxide of hydrogen, which may be called *peroxide
of copper*.

1. The suboxide of copper was first observed by Proust ; but

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* Dr. Lewis, Neuman's Chemistry, p. 61.

we are indebted to Mr. Chenevix, who found it native in Corn-wall, for the investigation of its properties. It may be prepared by mixing together 57·5 parts of black oxide of copper, and 50 parts of copper reduced to a fine powder by precipitating it from muriatic acid by an iron plate. This mixture is to be triturated in a mortar, and put with muriatic acid into a well-stopped phial. Heat is disengaged, and almost all the copper is dissolved. When potash is dropped into this solution, the oxide of copper is precipitated orange. But the easiest process is to dissolve any quantity of copper in muriatic acid by means of heat. The green liquid thus obtained is to be put into a phial, together with some pieces of rolled copper, and the whole is to be corked up closely. The green colour gradually disappears; the liquid becomes dark brown and opaque; and a number of dirty white crystals, like grains of sand, are gradually deposited. When this liquid, or the crystals, are thrown into a solution of potash, the orange-coloured oxide precipitates in abundance. The specific gravity of this oxide, as determined by Proust and Dumas, is 5·749.* But Mr. Harepath states it at 6·093;† which must be very near the truth, as the native crystallized suboxide has been found as high as 5·992.

The oxide of copper when exposed to a strong heat is converted into suboxide. I have a specimen of metallic copper which was converted into suboxide by frequent exposure to the heat at which gold melts. When this suboxide is digested in dilute acids it is converted into oxide which dissolves, and metallic copper which remains. But nitric acid converts it entirely into oxide, and muriatic acid dissolves it and forms with it a colourless solution, from which it is precipitated by an alkali in the state of a yellow hydrate. It dissolves in ammonia, and the solution is colourless. It is formed when caustic ammonia is digested on metallic copper. When the solution is exposed to the air the suboxide is converted into oxide, and the liquid assumes a violet blue colour. From the analysis of Chenevix and Berzelius, there can be no doubt that this suboxide is a compound of

Copper	.	.	8
Oxygen	.	.	1
			——
			9‡

2. The oxide of copper is easily procured pure from the

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* Annals of Philosophy (2d series) iii. 392.   † Phil. Mag. lxiv. 322.
‡ Berzelius's experiments make it

Copper	.	.	.	8
Oxygen	.	.	.	1·0108

scales which are formed upon the surface of red-hot copper. These scales have a violet red colour, owing to the presence of a little metallic copper upon their under surface; but when kept for some time red-hot in an open vessel, they become black, and are then pure oxide of copper. The same oxide may be obtained by dissolving copper in sulphuric or nitric acid, precipitating by means of potash, and then heating the precipitate sufficiently to drive off any water which it may retain. This oxide is a tasteless black powder, without any lustre. It dissolves in acids without effervescence, and forms green or blue coloured solutions according to the acid. Its specific gravity, as determined by Mr. Harepath, is 6·401.*.

When exposed to a very high temperature, it melts and assumes a crystallized texture. If we drop a solution of this oxide into a caustic alkaline ley, we obtain a blue coloured bulky precipitate which is a hydrated oxide, composed when dried in a very low heat of

$1\frac{1}{2}$ atom water	.	.	1·6875
1 atom oxide	.	.	5·

6·6875

The oxide of copper is insoluble in the caustic fixed alkaline leys. But when fused with the fixed alkalies or alkaline earths, a combination takes place which has either a green or a blue colour, according to circumstances. It even displaces carbonic acid at a red heat. When these compounds are digested in water, decomposition takes place, the alkaline body is dissolved, and the oxide of copper remains. Caustic ammonia dissolves this oxide, or at least its salts, and the solution has a fine and deep blue colour. If ammonia be poured upon pure oxide of copper in a well stopped vessel, to the interior of which air has no access, hardly any of the oxide of copper is dissolved, so that the ammonia scarcely becomes coloured. But if a single drop of carbonate of ammonia be added, and the whole shaken, the liquid immediately acquires a blue colour. This seems to show that what has hitherto been considered as a solution of oxide of copper in ammonia, is in reality a solution of a double cupreous salt in that alkali. If to this solution we add a sufficient quantity of caustic potash, the copper falls in the state of a blue hydrated oxide, and the liquid becomes colourless. The reason of this probably is that the potash takes possession

* Phil. Mag. lxiv. 322.

of the acid formerly united to the oxide of copper. This oxide dissolves in glass and gives it a green colour. It dissolves in oils, and colours them green.

I have shown elsewhere* that the oxide of copper is a compound of

Copper	. . 4
Oxygen	. . 1
	5

Now as this oxide constitutes the bases of all the salts of copper (for the existence of salts containing the suboxide is still far from being proved in a satisfactory manner), and as it is evident from the analysis of these salts that the atomic weight of the oxide is 5, unless we choose to consider all the cupreous salts as containing two atoms of acid united to one atom of oxide, which is not the case with any other genus of salts, we must consider this oxide as a compound of

1 atom copper	. . 4
1 atom oxygen	. . 1
	5

On that supposition the atomic weight of copper must be 4.†

3. When the hydrated oxide of copper is mixed with a dilute deutoxide of hydrogen at the temperature of 32°, the hydrate assumes first a greenish colour, and becomes at last yellowish brown, which is the colour of the peroxide of copper. As soon as this oxide is formed it begins to give out oxygen. This evolution is diminished by pouring water on it to dilute the deutoxide of hydrogen sufficiently. It must be separated as quickly as possible from the liquid, pressed between folds of paper, and then dried in a vacuum over sulphuric acid. When raised to the boiling point of water it is decomposed. When thrown on a red-hot coal it detonates, and the copper is reduced. It is insoluble in water, and does not alter the colour of litmus paper. Acids decompose it into oxide of copper and deutoxide of hydrogen. According to Thenard, to whom we are indebted

* First Principles, i. 412.

† This opinion has been adopted by almost all chemists. Berzelius, Wollaston, Gay-Lussac, Proust, Leopold Gmelin, &c. Dr. Turner, I observe, in his Elements of Chemistry (p. 545), has adopted a contrary opinion. But I have little doubt that when he fully considers the subject he will see reason to alter it.

for all the preceding facts, the peroxide contains twice as much oxygen as the oxide. Hence it consists of

1 atom copper	. .	4
2 atoms oxygen	. .	2
		—
		6

It is obvious that the suboxide is a compound of

2 atoms copper	. .	8
1 atom oxygen	. .	1
		—
		9

III. When copper filings are introduced into chlorine gas they take fire, a fixed yellowish substance is formed, while a portion sublimes in the state of a yellowish brown powder. The first of these compounds is a *subchloride of copper ;* the second a *chloride.*

1. The subchloride may be formed by heating a mixture of two parts of corrosive sublimate and one part of copper. Boyle obtained it in this way, and published an account of it in 1666 in his treatise on the *origin of forms and qualities,** under the name of *rosin of copper.* Proust obtained it by mixing proto-muriate of tin with a solution of copper in muriatic acid. He procured a white salt, to which he gave the name of *muriate of copper.*† Chenevix found afterwards that this salt is formed when equal weights of black oxide of copper, and copper in powder, are mixed together and then acted upon by muriatic acid in a close vessel.‡ Proust obtained it likewise by distilling green muriate of copper. A grayish mass remained in the retort, which was *subchloride of copper.* It is obtained also when a plate of copper is plunged into a bottle filled with green muriate of copper. The green colour gradually disappears and small white crystals are deposited, which consist of subchloride of copper.§

Subchloride of copper when pure has an amber colour and a certain degree of translucency. It melts at a heat just below redness. In close vessels it is not decomposed nor sublimed by a strong red heat, but in the open air it is dissipated in white fumes. It is insoluble in water; but dissolves in nitric acid without effervescence. In muriatic acid it dissolves without

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* Shaw's Boyle, i. 252, 255. † Ann. de Chim. xxviii. 218.
‡ Phil. Trans. 1801, p. 237. § Jour. de Phys. li. 181.

Chap. III.

effervescence, and is precipitated again unaltered by water. Potash throws down suboxide of copper. According to the analysis of Dr. John Davy,* it is composed of

2 atoms copper	.	.	8
1 atom chlorine	.	.	4·5

2. Chloride.

2. The *chloride of copper* may be obtained by evaporating the green muriate to dryness in a temperature not exceeding 400°. It has a brownish yellow colour, and is pulverulent. When exposed to the air it absorbs moisture, and becomes first white and then green. Heat decomposes it, driving off a portion of the chlorine and converting it into subchloride. According to the analysis of Dr. John Davy† it is composed of

1 atom copper	.	.	4
1 atom chlorine	.	.	4·5

IV. The combination which copper forms with bromine has not been examined.

Iodide.

V. Copper may be combined with iodine by heating the two substances together. Analogy would lead us to suppose that two *iodides* of this metal exist. But no experiments have hitherto been made on the subject. The only iodide known is of a dark brown colour. It may be obtained by dropping a hydriodate of potash into a solution of copper in an acid. This iodide is insoluble in water. It is probably a compound of

1 atom copper	.	.	4
1 atom iodine	.	.	15·75
			———
			19·75

We do not know the action of *fluorine* on copper. Copper does not combine, so far as is known, with hydrogen, azote, boron, or silicon.

Phosphurets.

VI. Mr. Pelletier formed *phosphuret of copper* by melting together 16 parts of copper, 16 parts of phosphoric glass, and 1 part of charcoal.‡ Margraff was the first person who formed this phosphuret. His method was to distil phosphorus and oxide of copper together. It is formed most easily by projecting phosphorus into red hot copper. It is of a white colour; and, according to Pelletier, is composed of 20 parts of phosphorus and 80 of copper,§ or 1 atom phosphorus, 2 atoms copper. This phosphuret is harder than iron. It is not ductile, and yet cannot easily be pulverized. Its specific gravity is

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* Phil. Trans. 1812, p. 170.   † Ibid.
‡ Ann. de Chim. i. 74.   § Ibid. xiii. 3.

7·1220. It crystallizes in four-sided prisms.* It is much more fusible than copper. When exposed to the air, it loses its lustre, becomes black, falls to pieces; the copper is oxidated, and the phosphorus converted into phosphoric acid. When heated sufficiently, the phosphorus burns, and leaves the copper under the form of black scoriæ.†

Sage has shown that this compound does not easily part with the whole of its phosphorus, though frequently melted, but retains about a twelfth. In this state it may be considered as a sub-phosphuret. It is more fusible than copper, and has the hardness, the grain, and the colour of steel, and admits of an equally fine polish.‡

M. H. Rose formed two other phosphurets of copper. The first by passing a current of dry phosphuretted gas over dry chloride of copper. The phosphuret was a compound of

1 atom phosphorus	2
1 atom copper	6
	—
	8

The other compound was a trisphosphuret formed by passing a current of phosphuretted hydrogen over hot subchloride of copper. It was a compound of

1 atom phosphorus	2
3 atoms copper	12
	—
	14§

VII. Copper and sulphur unite at least in three proportions, and probably even in a greater number. **Sulphurets.**

1. If 8 parts by weight of copper filings, mixed with 3 parts of flowers of sulphur, be put into a glass receiver, and placed upon burning coals, the mixture first melts, then a kind of explosion takes place; it becomes red hot; and when taken from the fire, continues to glow for some time like a live coal. If we now examine it, we find it converted into *sulphuret of copper.* This curious experiment was first made by the associated Dutch chemists, Dieman, Troostwyk, Niewland, Bondt, and Laurenburg, in 1793.‖ They found that the combustion succeeds best when the substances are mixed in the proportions mentioned above; that it succeeds equally, however pure and dry

* Sage, Jour. de Phys. xxxviii. 468.   † Fourcroy, vi. 252.
‡ Nicholson's Jour. ix. 268.   § Ann. de Chim. et de Phys. xxxiv. 172.
‖ Jour. de Min. No. ii. 85.

the sulphur and copper be, and whatever air be present in the glass vessel, whether common air, or oxygen gas, or hydrogen, or azotic gas, or even when the receiver is filled with water or mercury.

Disulphuret. It has been ascertained by analysis that this is a disulphuret composed of

1 atom sulphur . .	2
2 atoms copper . .	8
	—
	10

This sulphuret occurs native, and is known to mineralogists under the name of glance copper. It has a blackish lead gray colour, the metallic lustre, is very soft and sectile, and its specific·gravity is 5·695. Indeed Mr. Harepath states it as high as 5·792. It is usually crystallized in six-sided prisms, but from the observations made by Mr. Levy on the cleavage, it is not unlikely that its primary form may be a rhomboid somewhat analogous to the primary form of quartz.

Sulphuret. 2. Sulphuret of copper composed of an atom of each constituent is formed when a current of sulphuretted hydrogen gas is passed through a solution of sulphate of copper. The precipitate is at first brown; but it becomes gradually black. When dried it has a slight shade of green, and it slightly reddens moistened litmus paper. When heated it gives out a little moisture, then sulphurous acid and sulphur, and a disulphuret of copper remains behind. It is insoluble in caustic alkaline leys, and likewise in hydrosulphuret of ammonia. This sulphuret, which exists as a constituent of copper pyrites, is a compound of

1 atom sulphur . .	2
1 atom copper . .	4 .
	—
	6

Quintosul-phuret. 3. Berzelius informs us that when persulphuret of potassium (*hepar sulphuris*), is mixed with a solution of sulphate of copper, a liver brown precipitate falls, which may be washed without alteration by hot water, and which, when dry, assumes a black colour. He presumes that this matter is a compound of

5 atoms sulphur . .	10
1 atom copper . .	4
	—
	14

There can be little doubt that other analogous sulphurets of

copper might be formed by means of bisulphuret, tersulphuret, and quatersulphuret of potash.

VIII. When a current of selenietted hydrogen gas is passed through a solution of sulphate of copper, a precipitate falls in black flocks, which becomes gray when dry, and assumes a polish when rubbed with a hematite. This precipitate is probably a seleniet of copper. When heated half of the selenium is disengaged, and a melted mass remains, which is probably a subseleniet of copper. The same seleniet is obtained when copper and selenium are heated together. It has a steel gray colour, and melts long before it is heated to redness. When strongly heated, it gives out a portion of its selenium; but not the whole.*

IX. Copper may be combined with arsenic by fusing them together in a close crucible, while their surface is covered with common salt to prevent the action of the air, which would oxidize the arsenic. This alloy is white and brittle, and is used for a variety of purposes; but it is usual to add to it a little tin or bismuth. It is known by the names of *white copper* and *white tombac*. When the quantity of arsenic is small, the alloy is both ductile and malleable.†

Gehlen found that when 100 parts of copper filings and 100 parts of arsenic were melted together, a grayish white, brittle, fine granular mass was obtained weighing 158·5 parts. This is obviously a compound of

> 2 atoms copper,
> 1 atom arsenic.

X. Copper combines readily with antimony by fusion. The alloy is brittle when it consists of equal parts of the two metals, is of a beautiful violet colour, and its specific gravity is greater than intermediate.‡ This alloy was called *regulus of Venus* by the alchymists.

XI. Davy ascertained the fact that copper may be alloyed with potassium and sodium, and that the alloys formed decompose water. But their properties have not been particularly investigated.

We are not acquainted with the alloys which copper forms with the metallic bases of the alkaline earths and earths proper.

XII. Equal parts of molybdenum and copper formed an alloy

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* Berzelius, Ann. de Chim. et de Phys. x. 244.
† Neuman's Chem. p. 144. ‡ Gellert, p. 136.

which yielded to the hammer a little, but at length broke in pieces, exhibiting a granular texture, and a bluish colour mixed with red. It admitted of being filed; and the surface thus exposed was paler than copper, and did not lose its lustre by exposure to the air. Four parts of copper and 1½ molybdenum formed an alloy not very different in its properties; but when the metals were mixed in the proportion of 1 part copper and 2 molybdenum, the alloy was brittle, and of a reddish-gray colour. Nitric acid dissolved the copper, and left the white oxide of molybdenum.*

XIII. When 100 parts of copper were heated with 50 parts of tungstic acid, a copper red button was obtained approaching to brown in colour, spongy, and pretty ductile, and weighing 133 parts.† This approaches

9 atoms copper	.	.	36
1 atom tungsten	.	.	12·5
			48·5

XIV. Iron may be united to copper by fusion, but not without considerable difficulty. The alloy has been applied to no use. It is of a gray colour, has but little ductility, and is much less fusible than copper. Thenard has ascertained, that it is attracted by the magnet, even when the iron constitutes only $\frac{1}{10}$th of the alloy.‡ Mr. Levavasseur has published some observations, which render it probable that the variety of iron called *hot short* iron, because it is brittle when red-hot, sometimes owes its peculiarities to the presence of copper. This variety possesses a greater degree of tenacity than common iron, and therefore answers better for some purposes. It may be hammered when white hot. As soon as it cools, so far as to assume a brown colour, the forging must be stopped till it becomes of an obscure cherry-red, and then it may be continued till the iron is quite cold.§

XV. There is an alloy of copper and nickel manufactured at Suhl in Thuringia which has a white colour like silver, and which is employed for a variety of ornamental purposes. It would appear that this alloy is obtained by smelting an ore which is found in the neighbourhood, and which from Brande's analysis is composed of

* Crell's Annals, iii. p. 366.   † Elhuyarts.
‡ Ann. de Chim. l. 131.   § Ibid. xlii. 183.

		Family IV.
Copper	88	Sect. V.
Nickel	8·753	
Sulphur with some antimony . .	0·750	
Silica, alumina, and iron . . .	1·750	

$$99·253*$$

There is an alloy much used in China under the name of *Tutenag* or white copper. It is white and resembles silver, and is very sonorous when struck. It admits of a fine polish and is not easily tarnished. Its specific gravity was found by Dr. Fyfe to be 8.432. It is malleable at the ordinary temperature of the air and at a red heat; but at a white heat it is brittle. According to the analysis of Dr. Fyfe it is an alloy of

Copper	40·4
Zinc	25·4
Nickel	31·6
Iron	2·6

$$100·0†$$

XVI. The alloy of copper and cobalt is unknown.

XVII. Manganese unites readily with copper. The compound, according to Bergman, is very malleable, its colour is red, and it sometimes becomes green by age. Gmelin made a number of experiments to see whether this alloy could be formed by fusing the black oxide of manganese along with copper. He partly succeeded, and proposed to substitute this alloy instead of the alloy of copper and arsenic, which is used in the arts.‡

XVIII. The alloys of copper with cerium and uranium are unknown.

XIX. Zinc combines readily with copper, and forms one of the most useful of all the metallic alloys. The metals are usually combined together by mixing granulated copper, a native oxide of zinc called *calamine*, and a proper proportion of charcoal in powder. The heat is kept up for five or six hours, and then raised sufficiently high to melt the compound. It is afterwards poured into a mould of granite edged round with iron, and cast into plates. This compound is usually known in this country by the name of *brass*. The metals are capable of uniting in various proportions, and according to them, the colour and other qualities of the brass vary also. According to Dr. Lewis, who made

Brass.

* Schweigger's Jahrbuch, ix. 17.   † Edin. Philos. Journal, vii. 69.
‡ Gottingen Comment. 1787, vol. ix. p. 75.

Chap. III. numerous experiments on the subject, a very small portion of zinc dilutes the colour of copper, and renders it pale ; when the copper has imbibed one-twelfth of its weight the colour inclines to yellow. The yellowness increases with the zinc, till the weight of that metal in the alloy equals the copper. Beyond this point, if the zinc be increased, the alloy becomes paler and paler, and at last white.* The proportion of zinc imbibed by the copper varies in different manufactories according to the process, and the purposes to which the brass is to be applied. In some of the British manufactories the brass made contains $\frac{1}{5}$d of its weight of zinc. In Germany and Sweden, at least if the statements of Swedenburg be accurate, the proportion of zinc varies from $\frac{1}{3}$th to $\frac{1}{4}$th of the copper.†

The most intimate and complete alloy consists of two atoms of copper and one atom of zinc. This is British brass. Dutch brass, which answers so much better for the purposes of watchmakers, &c. appears to be a compound of four atoms copper and one atom zinc.

Brass is much more fusible than copper ; it is malleable while cold, unless the portion of zinc be excessive ; but when heated it becomes brittle. It is ductile, may be drawn out into fine wire, and is much tougher than copper, according to the experiments of Muschenbroeck.‡ According to Gellert, its specific gravity is greater than the mean. It varies considerably according to the proportion of zinc. Dr. Watson found a specimen of plate brass from Bristol 8·441:§ while Brisson makes common cast brass only 7·824. Brass may be readily turned upon the lathe, and indeed works more kindly than any other metal.

Pinchbeck. When zinc in the metallic state is melted with copper or brass, the alloy is known by the names of *pinchbeck, prince's metal, Prince Rupert's metal, similor,* &c. The proportion of zinc is equally variable in this alloy as in brass; sometimes amounting nearly to one-half of the whole, and at other times much less. The colour of pinchbeck approaches more nearly to that of gold, but it is brittle, or at least much less malleable than brass. Brass was known, and very much valued, by the ancients. They used an ore of zinc to form it, which they called

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* Neuman's Chem.   † Wasserberg, i. 267.

‡ But Mr. Rennie found that a bar of brass $\frac{1}{4}$ inch in diameter was broken by a weight of 1123 lbs. Hence a brass wire of one-tenth inch in diameter would be broken by a weight of 179·6 lbs. Hence it is weaker than cast brass. See Phil. Trans. 1818, p. 126.

§ Chem. Essays, iv. 58.

cadmia. Dr. Watson has proved that it was to brass which they gave the name of *orichalcum.** Their *æs* was copper, or rather bronze.†

XX. Copper and cadmium may be combined together. The alloy is white with a shade of yellow. It is very brittle, even when the proportion of cadmium amounts only to two or three hundred parts of that of the copper. When this alloy is exposed to a temperature sufficiently high to fuse copper, it is decomposed, and the whole cadmium is volatilized. Hence it is obvious, that brass never can contain any cadmium; while *tutty,* which is the matter sublimed during the making of brass, is sure to contain cadmium, if there was any of that metal present in the zinc ore. According to Stromeyer, the alloy of copper and cadmium is a compound of

Copper	.	.	100	. .	˙8
Cadmium	.	.	82	. .	6·56‡

It is probable from these numbers that the true chemical compound of copper and cadmium is composed of an atom of cadmium and two atoms copper.

XXI. Copper forms with bismuth a brittle alloy of a pale red colour, and a specific gravity exactly the mean of that of the two metals alloyed.§

XXII. Copper does not unite with melted lead till the fire is raised so high as to make the lead boil and smoke, and of a bright red heat. When pieces of copper are thrown in at that temperature, they soon disapper. The alloy thus formed is of a gray colour, brittle when cold, and of a granular texture.‖ According to Kraft, it is rarer than the mean.¶ The union between the two metals is very slight. When the alloy is exposed to a heat sufficient only to melt the lead, almost the

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* Manchester Transactions, vol. ii. p. 47.

† The ancients do not seem to have known accurately the difference between copper, brass, and bronze. Hence the confusion observable in their names. They consider brass as only a more valuable kind of copper, and therefore often used the word *æs* indifferently to denote either. It was not till a late period that mineralogists began to make the distinction. They called copper *æs cyprium,* and afterwards only *cyprium,* which in process of time was converted into *cuprum.* When these changes took place is not known accurately. Pliny uses *cyprium,* lib. xxxvi. cap. 26. The word *cuprum* occurs first in Spartian, who lived about the year 290. He says, in his life of Caracalla, *cancelli ex ære vel cupro.*

‡ Gilbert's Annalen, lx. 208.   § Gellert.

‖ Lewis, Neuman's Chem. p. 57.   ¶ Wasserberg, i. 263.

whole of the lead runs off, and leaves the copper nearly pure.* The little lead that remains may be scorified by exposing the copper to a red heat. If the lead that runs off carries with it any copper, on melting it the copper swims on the surface, and may be easily skimmed off.† This alloy is said to be employed sometimes for the purpose of making printers' types for very large characters.‡

Bronze.   XXIII. Tin unites very readily with copper, and forms an alloy exceedingly useful for a great variety of purposes. Of this alloy cannons are made : bell metal, bronze, and the mirrors of telescopes, are formed of different proportions of the same metals. The addition of tin diminishes the ductility of copper, and increases its hardness, tenacity, fusibility, and sonorousness. The specific gravity of the alloy is greater than the mean density of the two metals. It appears from the experiments of Mr. Briche, that this augmentation of density increases with the tin; and that the specific gravity, when the alloy contains 100 parts of copper and 16 of tin, is a maximum : it is 8·87. This is very nearly 12 atoms copper to 1 atom of tin. The specific gravity of equal parts of tin and copper is 8·79, but it ought only to be 8; consequently the density is increased 0·79.§ This alloy consists nearly of 2 atoms copper and 1 atom tin. In order to mix the two metals exactly, they ought to be kept a long time in fusion, and constantly stirred, otherwise the greater part of the copper will sink to the bottom, and the greater part of the tin rise to the surface; and there will be formed two different alloys, one composed of a great proportion of copper combined with a small quantity of tin, the other of a great proportion of tin alloyed with a small quantity of copper.

Bronze and the metal of cannons are composed of from 8 to 12 parts of tin combined with 100 parts of copper. This alloy is brittle, yellow, heavier than copper, and has much more tenacity; it is much more fusible, and less liable to be altered by exposure to the air. It was this alloy which the ancients

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* Lewis, Neuman's Chemistry, p. 57. This curious mode of separation is called in Chemistry *eliquation*.

† Ibid. p. 57.

‡ Fourcroy, vi. 266. It has been lately ascertained by Mr. Hatchett, that copper cannot be used to alloy gold unless it be free from lead. The smallest portion of this metal, though too minute to affect the copper itself, produces a sensible change on the ductility of gold.

§ Jour. de Min. An. v. 881.

used for sharp-edged instruments before the method of work-
ing iron was brought to perfection. The χαλκος of the Greeks,
and perhaps the *æs* of the Romans, was nothing else. Even
their copper coins contain a mixture of tin.*

The term *brass* is often applied to this alloy, though, in a
strict sense, it means a compound of copper and zinc. Brass
guns are made in no other part of Britain except Woolwich.
The proportion of tin varies from 8 to 12 to the 100 of copper;
the purest copper requiring the most, and the coarsest the
least. This alloy is more sonorous than iron; hence brass guns
give a much louder report than those made of cast iron.†

Bell metal is usually composed of 3 parts of copper and 1 **Bell metal.**
part of tin. Its colour is grayish white; it is very hard, son-
orous, and elastic. The greater part of the tin may be sepa-
rated by melting the alloy, and then pouring a little water on
it. The tin decomposes the water, is oxidized, and thrown
upon the surface. According to Swedenburg, the English bell
metal is usually made from the scoriæ of the brass gun foun-
dery, melted over again.‡ The proportion of tin in bell metal
varies. Less tin is used for church bells than clock bells;
and in small bells, as those of watches, a little zinc is added to
the alloy.§ According to Gerbert, the *conch* of the East Indians
is composed of tin and copper, in the same proportions as in
bell metal.‖

The alloy used for the mirrors of telescopes was employed **Mirror metal.**
by the ancients for the composition of their mirrors. It con-
sists of about 2 parts of copper, united to 1 part of tin. Mr.
Mudge ascertained, that the best proportions were 32 copper
to 14·5 of tin;¶ a specimen of an ancient mirror analyzed by
Klaproth was composed of

> 62 copper
> 32 tin
> 6 lead
> ———
> 100

But the lead he considers as accidental.** This alloy is very
hard, of the colour of steel, and admits of a fine polish. But

* See Dize's Analysis, Jour. de Phys. 1790.
† See Watson's Chem. Essays, iv. 127.   ‡ Wasserberg, i. 262.
§ Watson's Essays, iv. 132.   ‖ Wasserberg, i. 261.
¶ This is 6 atoms copper + 1 atom tin.
** Phil. Mag. xvii. 294.

besides this, there are many other compounds often used for the same purpose.*

Vessels of copper, especially when used as kitchen utensils, are usually covered with a thin coat of tin to prevent the copper from oxidating, and to preserve the food which is prepared in them from being mixed with any of that poisonous metal. These vessels are then said to be *tinned*. Their interior surface is scraped very clean with an iron instrument, and rubbed over with sal ammoniac. The vessel is then heated, and a little pitch thrown into it, and allowed to spread on the surface. Then a bit of tin is applied all-over the hot copper, which instantly assumes a silvery whiteness. The intention of the previous steps of the process is to have the surface of the copper perfectly pure and metallic; for tin will not combine with the oxide of copper. The coat of tin, thus applied, is exceedingly thin. Bayen ascertained, that a pan, nine inches in diameter, and three inches three lines in depth, when tinned, only acquired an additional weight of 21 grains. Nor is there any method of making the coat thicker. More tin indeed may be applied, but a moderate heat melts it, and causes it to run off.

SECTION VI.—OF BISMUTH.

History.   The ores of this metal are very few in number,† and occur chiefly in Germany. This, in some measure, accounts for the ignorance of the Greeks and Arabians, neither of whom appear to have been acquainted with bismuth. The German miners, however, seem to have distinguished it at a pretty early period, and to have given it the name of *bismuth ;* for Agricola, in his treatise entitled *Bermannus*, written at least as early as 1529, describes it under that name as well known in Germany, and considers it as a peculiar metal. The miners gave it also the name of *tectum argenti ;* and appear to have considered it as silver beginning to form, and not yet completed.‡ Mr. Pott collected, in his dissertation on bismuth, every thing respecting it contained in the writings of the alchymists. Beccher seems to have been the first chemist who pointed out some of its most

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* See Wasserberg, i. 262, and Watson's Chem. Essays, iv. 139.

† The number of species of bismuth ores known to mineralogists are 8, and some of these are very rare.

‡ Konig's Regnum Minerale, p. 80. Even so late as the end of the 17th century it was considered as a species of lead. There are three kinds of lead, says Etmuller; namely, common lead, tin, and bismuth. Bismuth approaches nearest to silver. Etmuller's Chemistry, p. 321.

remarkable properties. Pott's dissertation, published in 1739, contained an account of its habitudes with different chemical substances. Several additional facts were given by Neuman in his Chemistry, by Hellot and Dufay; but Geoffroy, junior, was the first who undertook a complete series of experiments on it. The first part of his labours was published in the Memoirs of the French Academy for 1753; but his death prevented the completion of his plan. Chemists for some time were disposed to consider bismuth as an alloy, but this opinion was gradually laid aside. Dr. John Davy, in 1812, published a set of careful experiments on the compounds which bismuth forms with oxygen, chlorine, and sulphur.* In 1813, Mr. Lagerhjelm published a set of experiments on its combinations with oxygen and sulphur.†

This metal is but little used; though it enters occasionally into some alloys. What exists in commerce is chiefly obtained from native bismuth ore. The process consists in merely melting the metal out of its gangue by exposing it to a moderate heat in contact with burning fuel. The metal, as it occurs in commerce, is never quite pure; but it may be rendered so by dissolving it in nitric acid, rendering the solution as neutral as possible by evaporation, and then diluting it with a good deal of water. A white curdy matter falls down, which must be well washed and dried in the open air. When this matter is heated in a charcoal crucible, or when it is mixed with black flux and heated in a Hessian crucible, it is reduced to pure metallic bismuth.

I. Bismuth is of a reddish white colour, and almost destitute both of taste and smell. It is composed of broad brilliant plates adhering to each other. The figure of its particles, according to Haüy, is an octahedron, or two four-sided pyramids, applied base to base.‡ Properties.

It is rather softer than copper. Its specific gravity is 9·822.§ According to Harepath, 9·833. By cautious hammering the specific gravity can be made as high as 9·8827, according to Berzelius.

When hammered cautiously, its density, as Muschenbroeck ascertained, is considerably increased. It is not, therefore, very brittle; it breaks, however, when struck smartly by a hammer, and consequently is not malleable. Neither can it be

* Phil. Trans. 1812, p. 169.   † Annals of Philosophy, iv. 357.
‡ Jour. de Min. An. v. p. 582.   § Brisson and Hatchett.

drawn out into wire. Its tenacity, from the trials of Muschen-broeck, appears to be such that a rod, $\frac{1}{10}$th inch in diameter, is capable of sustaining a weight of nearly 29 lbs.

When heated to the temperature of 476°* it melts, according to Dr. Irvine; but Mr. Crichton, junior, of Glasgow, who made a set of very careful experiments, some years ago, finds the melting point as high as 497°.

When allowed to cool slowly, and when the liquid metal is withdrawn, as soon as the surface congeals, it crystallizes in parallelopipeds, which cross each other at right angles.

Oxide.   II. When exposed to the air, it soon loses its lustre, but scarcely undergoes any other change. It is not altered when kept under water.

When kept melted in an open vessel, its surface is soon covered with a dark-blue pellicle; when this is removed, another succeeds, till the whole metal is oxidized. When these pellicles are kept hot and agitated in an open vessel, they are soon converted into a brownish or yellowish powder.

When bismuth is raised to a strong red heat, it takes fire and burns with a faint-blue flame, and emits a yellow smoke, as was first observed by Geoffroy. When this is collected, it is a yellow powder, not volatile, which has been called *yellow oxide of bismuth.*

When bismuth is dissolved in nitric acid, if water be poured into the solution, a white powder precipitates, which was formerly called *magistry of bismuth.* This powder is used as a paint, under the name of *pearl* or *flake-white.* Bucholz has demonstrated that this powder is a compound of oxide of bismuth and a little nitric acid. When this white matter is exposed to a red heat it is converted into pure oxide of bismuth.

Oxide of bismuth (for, as far as is known, it combines with only one proportion of oxygen,) is a straw yellow powder, destitute of taste and insoluble in water; but easily soluble in nitric acid. In a strong red heat it melts into a dark yellow opaque glass, which, on cooling, assumes its original colour. It is soluble in caustic fixed alkaline leys, and even somewhat soluble in caustic ammonia. I consider the experiments which I have elsewhere related† to prove that the atomic weight of oxide of bismuth is 10; and as it is the only oxide, we can have no hesitation in considering it as a compound of

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* Irvine, Nicholson's Jour. ix. 46.   † First Principles, i. 407.

1 atom bismuth	.	.	.	9
1 atom oxygen	.	.	.	1
				—
				10

So that the atomic weight of bismuth is 9.   Berzelius relying on the experiments of Lagerhjelm makes the oxide a compound of

Bismuth	.	.	.	8·871
Oxygen	.	.	.	1
				———
				9·871

But considering (for what reason does not appear) oxide of bismuth as a compound of 1 atom bismuth and $1\frac{1}{2}$ atom oxygen, he makes the atomic weight of bismuth 13·30376.

The specific gravity of oxide of bismuth, as determined by Roget and Dumas, is 8·449.[*]   I found the specific gravity of a portion of oxide which I had myself prepared 8·211.

Bismuth is sometimes used in the process of cupellation instead of lead.   It was first proposed for that purpose by Dufay in 1727, and his experiments were afterwards confirmed by Pott.[†]   This oxide is easily reduced when heated along with charcoal or other combustible bodies; for the affinity between bismuth and oxygen is but weak.

III. Bismuth takes fire when introduced into chlorine gas, Chloride. and forms a *chloride of bismuth*.   This compound has been long known under the name of butter of bismuth.   It is obtained by heating bismuth with corrosive sublimate.   By keeping it in fusion for an hour or two, at a temperature below the boiling point of mercury, that metal gradually subsides, and leaves the chloride of bismuth pure.   The chloride thus prepared has a grayish-white colour, is opaque, and of a granular texture, though not crystallized.   It does not sublime when heated to redness in a glass tube with a narrow orifice. According to the analysis of Dr. John Davy,[‡] to whom we are indebted for the preceding facts, this chloride is a compound of 4·5 chlorine and 8·89 bismuth.   It is evident from this that it is a compound of

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[*] Annals of Philosophy (2d series), iii. 392.
[†] See a set of experiments on this subject by Chaudet in the Ann. de Chim. et de Phys. viii. 113.
[‡] Phil. Trans. 1812, p. 190.

1 atom chlorine . . . 4·5
1 atom bismuth . . 9
_____
13·5

so that its atomic weight is 13·5.

Bromide.   IV. For the facts known respecting the bromide of bismuth
we are indebted to M. Serullas. To form it we must put
bismuth in powder, with a great excess of bromine, into a long
tube, shut at one extremity, and expose it to heat. Yellow
vapours appear and condense on the sides of the tube. These
Serullas considers as constituting a bromide containing more
bromine than the compound which remains at the bottom of the
tube, and which is a simple bromide of bismuth. It is a solid
of a steel-gray colour, having the aspect of iodine fused into
a solid mass. It fuses when heated to about 392°. It then
assumes a hyacinth red colour; but, upon being allowed to cool,
it resumes its former gray colour. When exposed to the air
it rapidly absorbs moisture, and assumes a fine sulphur yellow
colour. Water decomposes it into hydrobromic acid, and oxide
of bismuth still retaining bromine.

Bromide of bismuth may be obtained also by throwing bis-
muth, alloyed with $\frac{1}{4}$th of its weight of arsenic, into bromine,
contained in a tube. Combustion takes place, and two brom-
ides are formed. By applying heat the bromide of arsenic is
distilled over, while the bromide of bismuth, being by no means
volatile, remains behind.[*]

Iodide.   V. Iodine readily combines with bismuth by the assistance
of heat. The iodide has an orange-yellow colour; it is insoluble
in water; but may be dissolved in a solution of caustic potash
without occasioning any precipitation. This iodide has not been
analyzed, but there can be no doubt that it is a compound of

1 atom iodine . . 15·75
1 atom bismuth . . 9
_____
24·75

Hydret.   VI. When a bismuth wire from the negative pole of a gal-
vanic battery is plunged into water, into which a wire from the
positive pole also dips, it soon becomes black, and is covered
with black dendritical figures. This black matter is considered
as a hydret of bismuth.[†]

[*] Ann. de Chim. et de Phys. xxxviii. 323.
[†] Rutland; Schweigger's Journal, xv. 417.

VII. We are not acquainted with any combinations which bismuth forms with azote, carbon, boron, or silicon.

VIII. Bismuth cannot be easily combined with phosphorus. Mr. Pelletier attempted to produce the phosphuret of bismuth by various methods without success. When he dropped phosphorus, however, into bismuth in fusion, he obtained a substance which did not apparently differ from bismuth, but which, when exposed to the blowpipe, gave evident signs of containing phosphorus.* This substance, according to Pelletier, did not contain above four parts in the hundred of phosphorus, and even this small portion seems only to have been mechanically mixed. Phosphuretted hydrogen gas throws down bismuth in the state of a black powder, which yields phosphorus when distilled.†

IX. Sulphur combines readily with bismuth by fusion. The sulphuret of bismuth is of a bluish-gray colour. It crystallizes in beautiful tetrahedral needles, which cross each other. It is very brittle and fusible, and bears a strong resemblance to sulphuret of antimony, but is rather brighter coloured. One hundred parts of bismuth, according to Wenzel's experiments, unite by fusion to 17·5 of sulphur. Doubtless a portion of the metal had remained uncombined; for both Dr. John Davy and M. Lagerhjelm found this sulphuret a compound of 100 bismuth and 22·43 of sulphur. M. H. Rose analyzed native bismuth, which, though a very rare mineral, occurs both in Sweden and Germany, and found it a compound of

1 atom bismuth	.	:	.	9
1 atom sulphur	.	.	.	2

11‡

The specific gravity of this sulphuret, as determined by Mr. Harepath, is 7·591. Mohs states that of native sulphuret at 6·549.

X. Selenium and bismuth combine with the evolution of a small quantity of heat. The seleniet melts at a red heat. When cold it has the metallic lustre, a silver white colour, and a very crystalline texture.§

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* Ann. de Chim. xiii. 30.   † Berzelius.

‡ The result of his analysis was

Bismuth	.	.	80·98
Sulphur	.	.	18·72
			99·70

§ Berzelius, Ann. de Chim. et de Phys. x. 248.

XI. When arsenietted hydrogen gas is passed through a solution of bismuth an arseniet of bismuth is precipitated. When bismuth and arsenic are melted together almost the whole of the arsenic makes its escape. For, according to Bergman, the weight of the bismuth is only increased $\frac{1}{13}$th part. This would constitute an alloy of about

8 atoms bismuth	.	.	72
1 atom arsenic	.	.	4·75
			76·75

XII. With tellurium and antimony bismuth may be melted in every proportion.

XIII. The combination of bismuth and molybdenum is obstructed by the volatility of the former metal. When they are melted together, the bismuth is driven off, and a black brittle mass remains, consisting chiefly of molybdenum. Four parts of bismuth and one of molybdenum, being melted together in a bed of charcoal, gave a black brittle mass, together with a button of bismuth, which retained a portion of molybdenum. This button bore a few strokes of the hammer, but at length broke in pieces. Its texture was closer than bismuth, and it was very fusible.*

XIV. When 100 parts of bismuth, 50 of tungstic acid, and a quantity of charcoal powder, are strongly heated in a crucible, a button is obtained, which, with a few strokes of a hammer, extended itself easily, but on continuing them it split in pieces. This button weighed 142 grains.

XV. Bismuth and potassium unite readily together by heat. Serullas obtained this alloy by heating together a mixture of 60 parts of charred cream of tartar, 120 of bismuth, and 1 part of nitre. The alloy thus formed was rich in potassium. When broken it enters into fusion and burns. Serullas proposes it as an excellent test to prove the dryness of gases. When introduced into a gas containing the least moisture it is immediately affected.†

The other alloys of bismuth are still very imperfectly known. It constitutes one of the constituents of an alloy remarkable for its easy fusion. The most remarkable of the fusible metals is the one first made by Rose, and composed of

2 parts by weight of bismuth,			
1	.	.	of lead,
1	.	.	of tin.

* Crell's Annals, iii. p. 363.   † Ann. de Mines, viii. 151.

It melts when heated to 200°·75. Erman made a curious set
of experiments on the expansions of this metal, at different temperatures, of which I have given an account in a former work.* What is called Newton's fusible metal is an alloy of

    8 parts by weight of bismuth,
    5   .   .   of lead,
    3   .   .   of tin.

It melts at 212°.

SECTION VII.—OF MERCURY.

MERCURY or QUICKSILVER was known in the remotest ages. History. Indeed, as it occurs not unfrequently in a native state, it could not fail, at a very early period, to attract the attention of every person who was interested in metals. It is rather a rare metal, and occurs in the earth in only 5 different states, constituting 5 different species of mercurial ores. Native mercury is not uncommon, but by far the most abundant ore is cinnabar, or sulphuret of mercury.

The process followed for obtaining mercury from cinnabar Smelting process. is very simple; it is mixed with half its weight of lime, or of scales of iron, and distilled in an iron retort, or a kind of oven constructed for the purpose. The sulphur is abstracted by the lime, or iron, and the mercury passes over and is received in water. It comes over, for sale, in large iron bottles, and, so far as I have observed, while in the original packages, it is very pure. When we want pure quicksilver for any particular purpose, the usual way is to put a mixture of two parts of artificial cinnabar and 1 part of iron filings into a stone-ware retort, which is fitted into a receiver containing water. The retort is then gradually heated almost to redness. The mercury passes over into the receiver in a state of purity.

I. The colour of mercury is white, and similar to that of silver; Properties. hence the names *hydrargyrum, argentum vivum, quicksilver,* by which it has been known in all ages. It has no taste nor smell. It possesses a good deal of brilliancy; and, when its surface is not tarnished, makes a very good mirror. Its specific gravity is 13·568.†

Mr. Crichton, junior, of Glasgow, took its specific gravity

* On Heat and Electricity, p. 30.

† Cavendish and Brisson. The specific gravity varies considerably like that of all other metals. Fahrenheit found it 13·575. (Phil. Trans. 1724. vol. xxxiii. 114.) Mr. Biddle found it 13·613 at the temperature of 50°. (Phil. Mag. xxx. 134.)

with uncommon care, and obtained almost the very same result as Lord Charles Cavendish had done. He found it 13·56846. We may therefore consider 13·568 as the true specific gravity of pure mercury at the temperature of 60°. When in a solid state its density is increased; its specific gravity, according to the experiments of Schulz, being 14·391,* according to the experiments of Mr. Biddle 14·465.†

At the common temperature of the atmosphere it is always in a state of fluidity. In this respect it differs from all other metals. But it becomes solid when exposed to a sufficient degree of cold. The temperature necessary for freezing this metal is —38°·66, as was ascertained by the experiments of Mr. Hutchins‡ at Hudson's Bay. Solid mercury may be subjected to the blows of a hammer, and may be extended without breaking. It is therefore malleable; but neither the degree of its malleability, nor its ductility, nor its tenacity, have been ascertained.

Mercury boils when heated to 656°.§ It may, therefore, be totally evaporated, or distilled from one vessel into another. It is by distillation that mercury is purified from various metallic bodies with which it is often contaminated. The vapour of mercury is invisible and elastic like common air: like air, too, its elasticity is indefinitely increased by heat, so that it breaks through the strongest vessel. Geoffroy, at the desire of an alchymist, enclosed a quantity of it in an iron globe strongly secured by iron hoops, and put the apparatus into a furnace. Soon after the globe became red hot, it burst with all the violence of a bomb, and the whole of the mercury was dissipated. ‖ The specific gravity of vapour of mercury, as determined by Dumas, is 6·976.¶ From this determination, which must be very near the truth, it follows as a consequence that the atomic weight of mercury is 12·5. For the atomic weight of a gaseous body multiplied by ·5555 is equal to the specific gravity in the gaseous state. Now 12·5 × ·5555 = 6·9747, a number which almost coincides with that found by Dumas. This is far-

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* Gehlen's Jour. iv. 434.   † Phil. Mag. xxx. 134.

‡ Phil. Trans. 1783, p. 303. See also Mr. Cavendish's observations on Mr. Hutchins's experiments in the same volume of the Transactions.

§ Crichton, Phil. Mag. xiv. 49. According to Heinrich the boiling point is 658¼°. Schweigger's Journal, i. 214. These are the numbers marked upon the common thermometer; the true boiling point is 660°, as determined by Mr. Crichton, jun.

‖ Macquer's Chemistry.   ¶ Ann. de Chim. et de Phys. xxxiii. 351.

ther corroborated by another circumstance. I have shown elsewhere* that if we divide the number 0·376 by the specific heat of a body, the quotient will be the atomic weight of that body. Now the specific heat of mercury is 0·03 and $\frac{0·376}{0·03} = 12·533$.

Mr. Smithson has pointed out a very sensible test for detecting the presence of mercury. If a little of any oxide or saline compound of mercury be put in a drop of muriatic acid on gold, together with a little tin, the gold will be amalgamated by the mercury, and exhibit a white spot. Quantities of mercury may be rendered evident in this way that could not be so by any other means. When we wish to discover mercury in cinnabar by this process, we must first boil it with sulphuric acid in a platinum spoon to convert it into sulphate, and then proceed as before. If the mercury be in the metallic state, we must place it in a drop of nitric acid on gold, evaporate it to dryness, and then add muriatic acid and tin.† Test of.

II. Mercury is not altered by being kept under water. When exposed to the air, its surface is gradually tarnished, and covered with a black powder, owing to its combining with the oxygen of the atmosphere. But this change goes on very slowly, unless the mercury be either heated or agitated, by shaking it, for instance, in a large bottle full of air. By either of these processes the metal is converted into an oxide: by the last, into a black-coloured oxide; and by the first, into a red-coloured oxide. Oxides.

The oxides of mercury are two in number.

1. The suboxide was first described by Boerhaave. He formed it by putting a little mercury into a bottle, and tying it to the spoke of a mill-wheel.‡ By the constant agitation which it thus underwent, it was converted into a black powder, to which he gave the name of *ethiops per se*. It is a black powder without any of the metallic lustre, has a coppery taste, and is insoluble in water. When calomel is digested in an alkaline ley, a black powder is likewise obtained. This black powder has been hitherto considered as suboxide of mercury; but M. Guibourt affirms that it contains globules of running mercury, visible by means of a glass, and even to the naked eye when the metal is subjected to a strong pressure.§ Mr. 1. Suboxide.

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* On Heat and Electricity, p. 97.   † Annals of Philosophy, iv. 128.

‡ This experiment was first made by Homberg in 1699. He attached a bottle holding some mercury to the clapper of a mill. Martyn's Abridg. of the Par. Mem. vol. i.

§ Ann. de Chim. et de Phys. i. 422.

Donovan has shown that when a small quantity of calomel is mixed at once with a considerable quantity of potash ley the suboxide of mercury is obtained in a state of purity, provided we take care to remove the metallic globules of mercury with which it is mechanically mixed.*

Various experiments have been made to determine the composition of this oxide. The most accurate appear to be those of Seftstrom :† according to whom it is a compound of

Mercury	. .	100
Oxygen	. .	3·99

We may, without any sensible error, consider it as a compound of 100 mercury + 4 oxygen, or of 25 mercury and 1 oxygen. If the atom of mercury be 12·5, it is obvious that the suboxide is a compound of

2 atoms mercury	. .	25
1 atom oxygen	. .	1
		—
		26

so that an atom of it must weigh 26. This oxide has the property of combining with acids and constituting salts. In this respect it agrees with suboxide of copper. It has a specific gravity, according to Harepath, of 10·69. It is very easily reduced to the metallic state. Indeed it almost always contains globules of mercury (visible under a magnifier) mixed with it. But when combined with an acid it becomes more difficult to decompose it. When this oxide is heated or boiled in water it becomes green, being partly reduced and partly converted into peroxide.‡

2. Oxide.

2. When mercury, or its suboxide, is exposed to a heat of about 600°, it combines with additional oxygen, assumes a red colour, and is converted into an oxide. This oxide may be formed two different ways: 1. By putting a little mercury into a flat-bottomed glass bottle or matrass, the neck of which is drawn out into a very narrow tube, putting the matrass into a sand bath, and keeping it constantly at the boiling point. The height of the matrass, and the smallness of its mouth, prevents the mercury from making its escape, while it affords free access to the air. The surface of the mercury becomes gradually black, and then red, by combining with the oxygen of the air: and at the end of several weeks, the whole is converted into a

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* Annals of Philosophy, xiv. 244.   † Ibid. iii. 355.
‡ Donovan, Ibid. xiv. 244.

red powder, or rather into small crystals of a very deep red colour. The oxide, when thus obtained, was formerly called *precipitate per se.* 2. When mercury is dissolved in nitric acid, evaporated to dryness, and then exposed to a graduated heat, it assumes a brilliant scarlet colour. The powder thus obtained was formerly called *red precipitate,* and possesses exactly the properties of the oxide obtained by the former process.*

When formed by heat it frequently crystallizes in regular octahedrons. It has an acrid and disagreeable taste, possesses poisonous qualities, and acts as an escharotic when applied to any part of the skin. Its specific gravity, according to Harepath, is 11·085; but Roget and Dumas make it 11·29.† It is said to be somewhat soluble in water. But this is probably only the case when the nitrate of which it is formed has not been completely decomposed. When triturated with mercury, it gives out part of its oxygen, and the mixture assumes various colours, according to the proportion of the ingredients. When heated along with zinc or tin filings, it sets these metals on fire. When heated to redness it becomes black, without any change in its proportion of oxygen.‡ According to the experiments of Seftstrom,§ which I consider as the most accurate, this oxide is composed of 100 parts mercury and 7·99 parts oxygen. We may therefore, without sensible error, consider it as a compound of

1 atom mercury	. .,	12·5
1 atom oxygen	. .	1
		13·5

I have shown by experiments, which I consider as decisive, that the real atomic weight of mercury is 12·5.‖

III. Mercury takes fire when introduced into chlorine gas Chloride. and heated. It is capable of combining in two proportions with chlorine, and of forming two chlorides which have been long known. The subchloride is usually called *calomel,* and the chloride *corrosive sublimate.*

It would occupy too much room to give a detail of the very numerous experiments that have been made upon these chlo-

* See a description of the method of manufacturing this oxide, by Payssé. Ann. de Chim. li. 202.
† Annals of Philosophy (2d series), iii. 392.
‡ Donovan, Annals of Philosophy, xiv. 244.
§ Annals of Philosophy, iii. 355.
‖ Annals of Philosophy (2d series), ii. 126.

rides. Their composition was first established by Sir Humphrey Davy.

1. Chloride of mercury is usually denominated *corrosive sublimate*, or *corrosive muriate of mercury*. The original discoverer of it is unknown. It is mentioned by Geber, who lived in the 7th century. The Chinese have been acquainted with it also for a long time.* The alchymists appear all to have been acquainted with it, and to have reckoned it among their secrets; and some of them, Albertus Magnus for instance, describe it with a good deal of precision. Bergman has enumerated no less than 14 different processes recommended by chemists for preparing it; and since that time several new methods have been proposed.

The process most commonly followed is to mix together equal parts of dry nitrate of mercury, decrepitated common salt, and calcined sulphate of iron. One-third of a matrass is filled with this mixture; the vessel is placed in a sand-bath, and gradually heated to redness. When the apparatus is cold, corrosive sublimate is found sublimed in the upper part of the matrass. Another process, first proposed by Kunkel, is to expose, in a similar vessel, a mixture of equal parts of sulphate of mercury and dry common salt to a strong heat: corrosive sublimate is equally sublimed. It may be formed likewise by passing chlorine gas into a solution of nitrate of mercury, and evaporating the solution till the salt crystallizes.† But it would be tiresome and useless to enumerate all the different processes. By far the most simple, and certainly the best for chemical purposes, is to dissolve the red oxide of mercury in muriatic acid. The solution takes place readily, and without the disengagement of any gas; and the salt crystallizes spontaneously.‡

Chloride of mercury, when obtained by sublimation, is in the form of a beautiful white semi-transparent mass, composed of very small prismatic needles. By evaporation, it yields cubes or rhomboidal prisms, or more commonly quadrangular prisms with their sides alternately narrower, and terminated by dihedral summits.§ Mr. Brooke has shewn that the primary form of the crystals is a right rhombic prism, the faces of which are inclined at angles of 93° 44′ and 86° 16′.‖ Its specific

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* Bergman, iv. 281.   † Fourcroy, v. 337.
‡ Berthollet, Mem. de l'Instit. iii. 136.   § Bergman, iv. 295.
‖ Annals of Philosophy (2d series), vi. 285.

gravity is 5·1398.* Its taste is excessively acrid and caustic, and it leaves for a long time a very disagreeable styptic metallic impression on the tongue. When swallowed, it is one of the most virulent poisons known, producing violent pain, nausea, and vomiting, and corroding in a very short time the stomach and intestines † According to the experiments of Dr. Davy, 100 parts of water at 57°, dissolve 5·4 parts of corrosive sublimate.‡ The solubility increases rapidly with the temperature. Wenzel found that water boiled over it dissolves the third part of its weight of the salt.§ Alcohol of specific gravity 0·816 dissolves at 60° half its weight; and sulphuric ether at the same temperature, dissolves nearly one-third of its weight. The specific gravity of both the alcoholic and ether solutions is 1·08.‖

It is soluble in muriatic acid, but insoluble in sulphuric and nitric acids. It is decomposed by the fixed alkalies, and oxide of mercury precipitated of a yellow colour, which soon becomes a brick-red. This decomposition renders corrosive sublimate a useful test for ascertaining the presence of alkalies in solution. If liquid sublimate be dropped into a solution containing the smallest portion of alkali, the brick-red precipitate appears. The alkaline earths also decompose this salt. Several of the metals, or their sulphurets, decompose it also by the assistance of heat. This is the case in particular with arsenic, bismuth, antimony, and tin. These metals unite with the chlorine, and separate the mercury which combines with sulphur if it be present.

M. H. Rose has ascertained that the white precipitate which appears when a current of sulphuretted hydrogen gas is passed through an aqueous solution of corrosive sublimate, is a compound of .

Mercury	. .	81·80
Chlorine	. .	9·53
Sulphur	. .	8·67
		100·00¶

* Hassenfratz. Ann. de Chim. xxviii. 12.
† Hence it was called by the alchymists the *dragon.*
‡ Phil. Trans. 1822, p. 358.
§ Verwandtschaft, p. 310.
‖ Dr. Davy, Phil. Trans. 1822, p. 358.
¶ Ann. de Chim. et de Phys. xl. 46.

This is nearly equivalent to

3 atoms mercury	. .	37·5
1 atom chlorine	. .	4·5
2 atoms sulphur	. .	4
	.	46·0

We may therefore consider it as a compound of

2 atoms sulphuret of mercury,
1 atom chloride of mercury.

M. Bonsdorf has shewn that corrosive sublimate possesses the properties of an acid, and that it is capable of uniting with the chlorides of the alkalifiable bases, and forming with them salts. The nature and properties of these new salts will come under our consideration in a subsequent part of this work.

I have shewn by experiments which appear to me decisive, that this chloride is a compound of

1 atom chlorine	. .	4·5
1 atom mercury	. .	12·5
		17

Hence its atomic weight is 17.

Subchloride or calomel.

2. Subchloride of mercury is usually distinguished by the names of *calomel* and *mercurius dulcis*. I am ignorant who the original discoverer of it was. It seems to have been prepared by the alchymists; yet Crollius, so late as the beginning of the 17th century, speaks of it as a grand secret and mystery: but Beguin made the process public in 1608 in his *Tirocinium Chemicum*, in which he describes the salt under the name of *draco mitigatus*.* It appears from the observations of Mr. Whatton,† that the terms *calomelas* and *mercurius calomelanius*, was first used by Sir Theodore Turquet de Mayenne, a French physician, who was born in 1572, who settled in England in 1616, where he was physician to James I. and Charles I., and died in Chelsea in 1655. He had been proscribed by the Faculty of Medicine of Paris, because he had made use of antimonial medicines, contrary to their express prohibition.

The processes for preparing it, which are numerous, have been described by Bergman. The most usual is to triturate four parts of chloride of mercury with three parts of running

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* It has been known also by a variety of other names; such as, *sublimatum dulce, aquila alba, aquila mitigata, manna metallorum, panchymogogum minerale, panchymogogus quercetanus.*

† Annals of Philosophy (2d series), ii. 427.

mercury in a glass mortar, till the mercury is *killed*, as the apothecaries term it; that is to say, till no globules of the metal can be perceived; and the whole is converted into a homogeneous mass. This mixture is put into a matrass, and exposed to a sufficient heat in a sand bath. The dichloride is sublimed; mixed, however, usually with a little chloride, which is either removed by repeated sublimations and triturations, or by washing the salt well with water.

It may be prepared also in the humid way, by a process first suggested by Scheele, but corrected by Mr. Chenevix.

Scheele's method is to form a nitrate of mercury by dissolving as much mercury as possible in a given quantity of boiling nitric acid. A quantity of common salt, equal to half the weight of the mercury used, is then dissolved in boiling water, and the boiling nitrate is cautiously poured into it. A white precipitate falls, which is to be edulcorated with water till the liquid comes off without any taste, and then dried upon a filter.* Chenevix has shown that in order to obtain the subchloride by this process quite free from all mixture of subnitrate, it is necessary to mix the solution of common salt with some muriatic acid.

Subchloride of mercury is usually in the state of a dull white mass; but when slowly sublimed, it crystallizes in four-sided prisms, terminated by pyramids. From the observations of Mr. Brooke it appears that the primary form of the crystal is a square prism, the terminal angles and edges of which are usually replaced by faces.† It is tasteless, does not act as a poison, but possesses the properties of a purgative. It is by far the most important and useful of all the mercurial preparations in a medicinal point of view. Its specific gravity is 7·1758, according to Hassenfratz. In cold water it is not sensibly soluble. Rouelle found it soluble in 1152 parts of boiling water. But from the experiments of Vogel it would appear that it undergoes a kind of decomposition when water is boiled on it. The portion dissolved has been probably converted into corrosive sublimate.‡

When exposed to the air, it gradually becomes deeper coloured. When rubbed in the dark, it phosphoresces, as Scheele discovered. A stronger heat is required to sublime it than is necessary for the sublimation of perchloride. Chlorine

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* Scheele, i. 221.
† Annals of Philosophy (2d series), vi. 285.
‡ Schweigger's Jahrbuch, iii. 293.

gas converts it into chloride; and the same change is produced by subliming it with one part of common salt and two parts of sulphate of iron. Nitric acid dissolves it readily, and much nitrous gas is evolved, as Berthollet has shown, and the salt is converted into a chloride.

Though the analyses of calomel by Zaboada, Chenevix, Stromeyer, Proust, and myself are not quite accurate, yet they leave no doubt that it is a compound of

2 atoms mercury . .	25
1 atom chlorine •	4·5
	29·5

so that its atomic weight is 29·5. It is analogous to the sub-oxide of mercury.

IV. M. Balard has shewn that mercury and bromine combine in two proportions, forming two bromides analogous to the chlorides.

1. When an alkaline hydrobromate is mixed with a solution of protonitrate of mercury, a white precipitate falls analogous to calomel, and doubtless a compound of

1 atom bromine . .	10
2 atoms mercury . .	25
	35

2. When bromine and mercury are placed in contact, they readily combine, heat being evolved; but no light. The bromide produced is a white matter, which may be sublimed by heat, and which is soluble in water and in alcohol, and very soluble in ether. Alkalies throw down a red or yellow precipitate from its aqueous solution. When treated with nitric or sulphuric acid, it gives out vapours of bromine.* Its constituents are

1 atom bromine . .	10
1 atom mercury . .	12·5
	22·5

V. Iodine combines readily with mercury. Nothing more is necessary than to place the two bodies in contact. They speedily unite. Iodide of mercury is formed likewise when a hydriodate is dropped into a solution of mercury in an acid. According to Gay-Lussac there are two iodides of mercury.

* Balard, Ann. de Chim. et de Phys. xxxii. 360.

The *subiodide* has a yellow colour, the *iodide* is a beautiful red, which may be employed as a paint. They are both insoluble in water. They are decomposed by nitric acid. Gay-Lussac has shown that the subiodide is a compound of

1 atom iodine	. .	15·75
2 atoms mercury	. •.	25
		40·75

and the iodide of

1 atom iodine	. .	15·75
1 atom mercury,	. .	12·5
		28·25

Phosphuret.

VI. Mr. Pelletier, after several unsuccessful attempts to combine phosphorus and mercury, at last succeeded by distilling a mixture of red oxide of mercury and phosphorus. Part of the phosphorus combined with the oxygen of the oxide, and was converted into an acid; the rest combined with the mercury. He observed, that the mercury was converted into a black powder before it combined with the phosphorus. On making the experiment, I found that phosphorus combines very readily with the black oxide of mercury, when melted along with it in a retort filled with hydrogen gas to prevent the combustion of the phosphorus. Phosphuret of mercury is of a black colour, of a pretty solid consistence, and capable of being cut with a knife. When exposed to the air, it exhales vapours of phosphorus.*

Sulphurets.

VII. Mercury combines with two proportions of sulphur, and forms two sulphurets. The *disulphuret* is *black*, but the *sulphuret* is *red*.

1. Disulphuret.

1. When two parts of sulphur and one of mercury are triturated together in a mortar, the mercury gradually disappears, and the whole assumes the form of a black powder, formerly called *ethiops mineral.* It is scarcely possible by this process to combine the sulphur and mercury so completely, that small globules of the metal may not be detected by a microscope. When mercury is added slowly to its own weight of melted sulphur, and the mixture is constantly stirred, the same black compound is formed. It may be obtained very readily likewise by passing a current of sulphuretted hydrogen gas through an acid solution of mercury. The black sulphuret is precipitated

* Ann. de Chim. xiii. 122.

abundantly. According to Guibourt running mercury may be pressed out of the sulphuret prepared in this way.* This sulphuret, according to Guibourt, is a compound of 25 mercury and 2·05 sulphur. Hence it obviously consists of

1 atom sulphur	. .	2
2 atoms mercury	. .	25
		27

This disulphuret is thrown down when a current of sulphuretted hydrogen is passed through a solution of protonitrate of mercury.

2. Sulphuret.   2. When ethiops mineral is heated red-hot, it sublimes; and if a proper vessel be placed to receive it, a cake is obtained of a fine red colour. This cake was formerly called *cinnabar;* and when reduced to a fine powder, is well known in commerce under the name of *vermilion.*†

This sulphuret of mercury has a scarlet colour, more or less beautiful, according to the mode of preparing it. Its specific gravity is about 10. It is tasteless, insoluble in water, and in muriatic acid, and not altered by exposure to the air. When heated sufficiently, it takes fire, and burns with a blue flame. When mixed with half its weight of iron filings, and distilled in a stone-ware retort, the sulphur combines with the iron, and the mercury passes into the receiver, which ought to contain water. By this process mercury may be obtained in a state of purity. The use of this sulphuret of mercury as a paint is well known.‡

Cinnabar may be prepared by various other processes. One of the simplest of these is the following, discovered by Mr. Kirchoff. When 300 grains of mercury and 68 of sulphur, with a few drops of solution of potash to moisten them, are triturated for some time in a porcelain cup by means of a glass pestle, ethiops mineral is produced. Add to this 160 grains of potash dissolved in as much water. Heat the vessel containing the ingredients over the flame of a candle, and continue the trituration without interruption during the heating. In proportion as the

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* Ann. de Chim. et de Phys. i. 424.

† The word *vermilion* is derived from the French word *vermeil,* which comes from *vermiculus,* or *vermiculum:* names given in the middle ages to the *kermes* or *coccus illicis,* well known as a red dye. *Vermilion* originally signified the red dye of the kermes. See Beckman's History of Discoveries, ii. 180.

‡ See a description of the process of making it by Payssé, Ann. de Chim. li. 196; and by Tuckert, ibid. iv. 25.

liquid evaporates, add clear water from time to time, so that the oxide may be constantly covered to the depth of near an inch. The trituration must be continued about two hours ; at the end of which time the mixture begins to change from its original black colour to a brown, which usually happens when a large part of the fluid is evaporated. It then passes very rapidly to a red. No more water is to be added ; but the trituration is to be continued without interruption. When the mass has acquired the consistence of a jelly, the red colour becomes more and more bright, with an incredible degree of quickness. • The instant the colour has acquired its utmost beauty, the heat must be withdrawn, otherwise the red passes to a dirty brown. Count de Moussin Pouschkin has discovered, that its passing to a brown colour may be prevented by taking it from the fire as soon as it has acquired a red colour, and placing it for two or three days in a gentle heat, taking care to add a few drops of water, and to agitate the mixture from time to time. During this exposure the red colour gradually improves, and at last becomes excellent. He discovered also, that when this sulphuret is exposed to a strong heat, it becomes instantly brown, and then passes into a dark violet ; when taken from the fire, it passes instantly to a beautiful carmine red.* Guibourt has shown that cinnabar is a compound of 25 mercury and 4 sulphur.† Hence it obviously consists of

1 atom sulphur'	.	2
1 atom mercury	.	12·5

14·5

VIII. When selenium and mercury are heated together, they unite without the evolution of any light. If there be an excess of mercury, it is easily driven off by distillation. The seleniet is a tin-white coherent mass. It does not melt, but sublimes, when heated, in white plates, which have the metallic lustre. It is scarcely attacked by nitric acid. · By long continued boiling in that acid, however, it is at length converted into seleniate of mercury. When muriatic acid is poured upon this white powder, it dissolves the mercury brought to the state of peroxide at the expense of the selenic acid, and selenium remains in the state of a red powder. Nitro-muriatic acid dissolves this seleniet with great rapidity, even without the assistance of heat.‡

Seleniet.

* Nicholson's Journal, ii. 1.   † Ann. de Chim. et de Phys. i. 425.
‡ Berzelius, ibid. x. 247.

IX. Mercury may be amalgamated with arsenic by keeping them for some hours over the fire, constantly agitating the mixture. The amalgam is gray-coloured, and composed of 5 parts of mercury and 1 of arsenic.* This approaches

2 atoms mercury	. .	25
1 atom arsenic	. .	4·75
		————
		29·75

X. Mercury may be amalgamated with tellurium by trituration.

XI. Pott first observed that antimony, reduced from its sulphuret by means of iron and chalk, unites readily with mercury by trituration. Antimony may be easily amalgamated by pouring it while in fusion into mercury almost boiling hot.† When 3 parts of mercury are mixed in this manner with 1 part of melted antimony, a soft amalgam is obtained, which very soon decomposes of itself.‡ Gellert also succeeded in forming this amalgam.§

XII. The attempts to combine mercury with chromium, molybdenum, tungsten, and titanium, have been unsuccessful.

XIII. Mercury may be readily amalgamated with potassium and sodium, either by heat or by simply placing the two bodies in contact. Considerable heat is evolved during the combination. The amalgam is solid, unless the proportion of potassium or sodium be very small. It crystallizes and has a white colour like that of mercury. The potassium or sodium is speedily converted into alkali in the open air or under water.‖

XIV. Mercury has been amalgamated with the metallic bases of the alkaline earths, by Seebeck, Berzelius, and Davy. But these amalgams have not been examined.

We are unacquainted with the compounds which mercury is capable of forming with the bases of the earths proper.

XV. Iron is not acted on by mercury: accordingly this last metal is usually kept in vessels of iron. Mr. Arthur Aiken, however, has shown that these two metals may be combined together. To form an amalgam of iron, he triturates together iron filings and the amalgam of the metal called *zinc,* and adds to the mixture a solution of iron in muriatic acid. By kneading

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* Bergman, ii. 281.   † Lewis, Neuman's Chem. p. 131.
‡ Wallerius.   § Metall. Chem. p. 141.
‖ Gay-Lussac and Thenard; Recherches Physico-chimiques, i. 222.

this mixture, and heating it, the iron and mercury which combine together gradually assume the metallic lustre.*

XVI. Mercury does not combine with nickel, or cobalt, or manganese. We are ignorant of the action of this metal on cerium and uranium.

Dr. Blainville has observed that when iron, nickel, or cobalt are previously alloyed with arsenic, the alloy very readily amalgamates with mercury.†

XVII. The amalgam of zinc was examined by Malouin. According to him, it is formed most readily by pouring mercury upon zinc, heated so as to char paper, but not to burn it. Its consistence varies with the proportion of zinc. Eight parts zinc, and 1 mercury, form a white very brittle compound. One zinc and $2\frac{1}{2}$ mercury form an alloy, which, when melted and cooled slowly, crystallizes. This amalgam is used to promote the excitement of electric machines.‡

XVIII. Mercury dissolves cadmium with the greatest facility, even without the assistance of heat. The amalgam has a silver-white colour, and crystallizes in octahedrons. Its specific gravity is greater than that of mercury. It melts when put into water of the temperature 167°. This amalgam is composed of

Mercury	. .	100	. .	25
Cadmium	. .	27·7778	. .	6·94445

Now 25 is the weight of 2 atoms of mercury, and 7 of an atom of cadmium. It is obvious therefore that the amalgam is a compound of 2 atoms mercury $+$ 1 atom cadmium.§

XIX. Mercury combines readily with bismuth, either by triturating the metals together, or by pouring 2 parts of hot mercury into 1 part of melted bismuth. This amalgam is at first soft, but it becomes gradually hard. When melted and cooled slowly, it crystallizes.

When the quantity of mercury exceeds the bismuth considerably, the amalgam remains fluid, and has the property of dissolving lead, and rendering it also fluid. This curious fact was first described by Beccher, who affirmed that a mixture of 3 parts mercury, 1 lead, and 1 bismuth, form a perfectly fluid amalgam. This triple compound may be filtered through shamois leather without decomposition. Mercury is sometimes adulterated with these metals; but the imposition may be easily

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* Phil. Mag. xiii. 416. † Jour. de Phys. lxxxiv. 267.
‡ It was first recommended for that purpose by Dr. Higgins. See Phil. Trans. 1778, p. 861.
§ Stromeyer; Gilbert's Annalen, lx. 209.

detected, not only by the specific gravity of the mercury, which is too small, but because it *drags a tail*, as the workmen say; that is, when a drop of it is agitated on a plain surface, the drop does not remain spherical, but part of it adheres to the surface, as if it were not completely fluid, or as if it were enclosed in a thin pellicle. This amalgam is used hot for silvering glass balls.

XX. Mercury amalgamates readily with lead in any proportion, either by triturating with lead filings, or by pouring it upon melted lead. The amalgam is white and brilliant, and when the quantity of lead is sufficient, assumes a solid form. It is capable of crystallizing. The crystals are composed of 1 part of lead and 1½ of mercury.*

XXI. Mercury dissolves tin very readily cold; and these metals may be combined in any proportion by pouring mercury into melted tin. The amalgam of tin, when composed of 3 parts of mercury and 1 of tin, crystallizes in the form of cubes, according to Daubenton: but, according to Sage, in gray brilliant square plates, thin towards the edges, and attached to each other, so that the cavities between them are polygonal.

This alloy is used in *silvering* the backs of looking-glasses. A sheet of tinfoil is spread upon a table, and mercury rubbed upon it with a hare's foot, till the two metals incorporate; then a plate of glass is slid over it, and kept down with weights. The excess of mercury is driven off, and in a short time the tinfoil adheres to the glass and converts it into a mirror.†

XXII. Mercury acts but feebly upon copper, and does not dissolve it while cold; but if a small stream of melted copper be cautiously poured into mercury heated nearly to the boiling point, the two metals combine and form a soft white amalgam.‡ Boyle pointed out the following method, which succeeds very well: triturate together 2 parts of mercury, 2½ parts of verdigris, and 1 part of common salt, with some acetous acid, and keep them for some time over a moderate fire, stirring them constantly, and supplying acid as it evaporates; then wash the amalgam and pour it into a mould; it is at first nearly fluid, but in a few hours it crystallizes and becomes quite solid.§ This amalgam may be formed also by keeping plates of copper in a solution of mercury in nitric acid. This plate is soon

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* Dijon Academicians.

† See Watson's Chem. Essays, p. 240. Dr. Watson has rendered it probable that the art of forming mirrors by coating glass with a plate of metal was known at least as early as the first century.

‡ Lewis, Neuman's Chem. p. 65.   § Shaw's Boyle, i. 343.

impregnated with mercury. The amalgam of copper is of a white colour, and so soft at first that it takes the most delicate impressions; but it soon becomes harder when exposed to the air. It is easily decomposed by heat; the mercury evaporates, and leaves the copper.

SECTION VIII.—OF SILVER.

Silver seems to have been known almost as early as gold; History. and doubtless for the same reason; because it occurs very frequently native, and requires no very high temperature to melt it. We find mention made of it in the book of Job, which is probably the oldest of the books contained in the Old Testament.

The ores of silver which have been examined and described by mineralogists, amount to 17 species. But by far the most abundant of them are native silver and sulphuret of silver.

A considerable quantity of silver is extracted from lead by How obtained. cupellation, as was described when treating of lead. This silver is very pure; the only foreign body not separated by the cupellation is gold. But gold occurs very rarely in lead ores, and is not likely therefore to be present. From those mines which contain native silver interspersed in stony matter, it is extracted by reducing the matter to powder and then mixing it with mercury in a kind of barrels along with water, the whole being agitated by machinery. By this means the silver is dissolved in the mercury, which is separated and distilled in proper vessels. The mercury passes over, and the silver remains behind.

When the silver is in combination with sulphur the ore is mixed with common salt and roasted, by which process it is converted into chloride of silver and sulphuret of sodium. Then water and iron are added, to get rid of the chlorine, and the silver thus disengaged is finally dissolved in mercury, and the amalgam treated as above mentioned.

When chemists wish to obtain pure silver for any particular purpose, they dissolve the silver of commerce in pure nitric acid, and throw it down from the solution by common salt. The precipitate must be well washed with boiling water and then dried. Put into a crucible twice as much potash as you have chloride of silver to reduce. Bring the potash to a state of complete fusion, and then introduce the chloride of silver by a little at a time, and it will be reduced. When the whole silver has been reduced, raise the heat sufficiently to melt it into a button, and then, when all is cold, wash off the potash,

and the silver will be found in a mass at the bottom of the crucible.

I. Silver is a metal of a fine white colour with a shade of yellow, without either taste or smell; and in point of brilliancy is inferior to none of the metallic bodies, if we except polished steel. It is softer than copper, but harder than gold. When melted, its specific gravity is 10·474;* when hammered 10·510.†

In malleability it is inferior to none of the metals, if we except gold. It may be beat out into leaves only $\frac{1}{100000}$ inch thick. Its ductility is equally remarkable: it may be drawn out into a wire much finer than a human hair; so fine indeed, that a single grain of silver may be extended about 400 feet in length. Its tenacity is such, that a wire of silver 0·078 inch in diameter is capable of supporting a weight of 187·13 lbs. avoirdupois without breaking.‡

Silver melts when it is heated completely red hot; and while melted its brilliancy is much increased. According to the calculation of Mortimer and Bergman, its fusing point is 1000° of Fahrenheit. But Mr. Princep found, by experiment, that the temperature at which silver melts, measured by an air thermometer, is 1830°. If the heat be increased after the silver is melted, the liquid metal boils, and may be volatilized; but a very strong and long-continued heat is necessary. Gasto Claveus kept an ounce of silver melted in a glass-house furnace for two months, and found, by weighing it, that it had sustained a loss of $\frac{1}{12}$th of its weight.§ Vauquelin, however, found that when placed upon charcoal, urged by a current of oxygen gas, the silver was volatilized in a visible smoke.‖

When cooled slowly, its surface exhibits the appearance of crystals; and if the liquid part of the metal be poured out as soon as the surface congeals, pretty large crystals of silver may be obtained. By this method Tillet and Mongez, junior, obtained it in four-sided pyramids, both insulated and in groups.

II. Silver is not oxidized by exposure to the air: it gra-

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* Brisson and Hatchett. Fahrenheit found it 10·481. (Phil. Trans. 1724, vol. xxxiii. p. 114.) I found pure silver melted and slowly cooled of the specific gravity 10·3946; when hammered it became 10·4177; when rolled out into a plate it became 10·4812. Nicholson's Jour. xiv. 397.

† According to Brisson. Muschenbroeck found the specific gravity of hammered silver 10·500. Dr. Lewis makes it no less than 10·980. (Phil. Com. p. 549.)

‡ Ann. de Chim. xxv. 9.

§ Theatrum Chem. ii. 17.   ‖ Ann. de Chim. lxxxix. 239.

dually indeed loses its lustre, and becomes tarnished; but this is owing to a different cause. Neither is it altered by being kept under water. But if it be kept for a long time melted in an open vessel, it gradually attracts oxygen from the atmosphere, and is converted into an oxide. This experiment was first made by Junker, who converted a quantity of silver into a vitriform oxide.* It was afterwards confirmed by Macquer and Darcet. Macquer, by exposing silver 20 times successively to the heat of a porcelain furnace, obtained a *glass*† of an olive green colour.‡ Nay, if the heat be sufficient, the silver even takes fire, and burns like other combustible bodies. Van Marum made electric sparks from his powerful Teylerian machine pass through a silver wire; the wire exhibited a greenish white flame, and was dissipated into smoke. Before a stream of oxygen and hydrogen gas, it burns rapidly with a light green flame. By means of the galvanic battery it may be burnt with great brilliancy.

Mr. Chevillot has shown that when silver is kept for some time in a state of fusion, in the open air, and then poured into water, it gives out a little oxygen gas. If it be alloyed with copper this evolution of oxygen does not take place.§

From the experiments of Ritter and Faraday, it would appear that, besides the common brown oxide of silver, which constitutes the basis of the salts of silver, there exist two other oxides not capable of uniting with acids, one of which is a *suboxide*, and the other a *superoxide*.

1. When silver is dissolved in nitric acid, and an alkali dropt into the solution, a brown coloured precipitate falls in flocks, which, when washed and dried, constitutes the *oxide* of silver. Its colour is grayish brown, and it becomes darker when dried. Its specific gravity, as determined by Mr. Harepath, is 7·143. From the experiments of Gay-Lussac and Thenard, it appears that this oxide does not combine with water nor form a hydrate. When exposed to the direct rays of the sun it gives out oxygen gas, and is converted into a black powder, the nature of which has not been examined. Whether it be soluble in fixed alkaline leys has not been ascertained. But when digested in caustic ammonia it is partly dis-

* Junker's Conspectus Chem. i. 887.
† Metallic oxides, after fusion, are called glass, because they acquire a good deal of resemblance, in some particulars, to common glass.
‡ Macquer's Dictionary, ii. 571.
§ Ann. de Chim. et de Phys. xiii. 299.

solved, while a black powder remains, constituting *fulminating silver*. From the experiments of Bucholz it would appear to be slightly soluble in barytes water.

From a very careful set of experiments on nitrate of silver, I have satisfied myself that the atomic weight of this oxide is 14·75. Now, as it is the only oxide that unites with acids, there is reason to consider it as a compound of

$$
\begin{array}{lll}
\text{1 atom silver} & . \quad . & 13\text{·}75 \\
\text{1 atom oxygen} & . \quad . & 1 \\
\hline
& & 14\text{·}75
\end{array}
$$

According to this supposition, the atomic weight of silver is 13·75.

The result of Berzelius's analysis of this oxide is that it is a compound of 93·112 silver and 6·888 oxygen. He has therefore fixed upon 13·51607 as the atomic weight of silver. With this result the experiments of Gay-Lussac and Davy nearly coincide; while those of Rose, Proust, and Bucholz, approach very nearly to mine. The difference between 13·5 and 13·75 is so small that it is not easy to determine accurately between them.

Suboxide.   2. When oxide of silver is dissolved in ammonia and the solution left exposed to the open air, it is soon covered with a brilliant pellicle. If this be removed another soon succeeds, and the process goes on till almost all the oxide of silver has undergone the change in question. When this matter is viewed by reflected light its colour is gray, and it is very brilliant; by transmitted light it appears of a bright brown. When suddenly heated it melts, gives out oxygen, and leaves a button of silver. Mr. Faraday, who first turned his attention to this brilliant pellicle, analyzed a quantity of it by exposing it to heat and collecting the oxygen gas evolved. By this process he resolved it into

7·5 oxygen and about 150 silver.
While in a comparative experiment he reduced the common oxide of silver into

7·5 oxygen and 101·6 of silver.
It is obvious that if we suppose the silver to be identical in the two oxides, the oxygen in the common oxide will be to that in the brilliant pellicle, as the numbers 3 to 2. So that if the first contain 1 atom oxygen, the second will contain $\frac{2}{3}$ds of an atom. Or we may view the pellicle as a compound of

$1\frac{1}{2}$ atom silver   .   .   20·625

1   atom oxygen   .   .   1

21·625*

It is therefore a suboxide of silver. We have no evidence that this suboxide is capable of uniting with acids and forming salts.

3. The *superoxide* of silver was discovered by Ritter.† Superoxide. When a platinum wire from the positive extremity of a galvanic battery is plunged into a weak solution of nitrate of silver, soon after the circuit is completed small crystals about 3 or 4 lines in length, and very brilliant, appear on the platinum wire. These crystals, according to Grothuss, have the form of octahedrons. Their colour is iron black. When held to the flame of a candle they detonate and leave metallic silver. When put into muriatic acid chlorine is evolved, and they are instantly converted into chloride of silver. When dissolved in ammonia, azotic gas is evolved, and they are converted into common oxide of silver. When digested in phosphoric and sulphuric acids, oxygen gas is evolved, and common phosphate and sulphate of silver formed. These facts, for which we are indebted to Ritter, render it exceedingly probable that this oxide contains more oxygen than the common oxide. But the subject requires farther investigation; and it is to draw the attention of chemists to it that I mention it here.

III. Silver does not burn when heated in chlorine gas; but Chloride. it gradually absorbs the gas, and is converted into the well known compound called formerly *horn silver*, and more lately distinguished by the name of *muriate of silver*. Sir H. Davy first showed that it is a *chloride of silver*.

This chloride is easily obtained by dissolving silver in nitric acid, and mixing the solution with a solution of common salt. A copious curdy precipitate falls. When this precipitate is washed and dried it constitutes pure chloride of silver. Its specific gravity, as determined by Mr. Harepath, is 5·129. The specific gravity of native chloride of silver, as determined by Mohs, is 5·552. It may be crystallized in octahedrons.

This chloride is one of the most insoluble substances known: according to Monnet it requires no less than 3072 parts of water to dissolve it. When exposed to the air, it gradually acquires a purple colour. When exposed to a heat of about 500°, it melts, and assumes, on cooling, the form of a gray-

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* Faraday, Journal of Science, iv. 268.   † Gehlen's Journal, iii. 563.

coloured semitransparent mass, having some resemblance to horn, and for that reason called *luna cornea.* A strong heat sublimes it, as Margraff ascertained.* When heated strongly in an earthen crucible, it passes through altogether, and is lost in the fire; but when mixed with about four times its weight of fixed alkali, formed into a ball with a little water, and melted rapidly in a crucible well lined with alkali, the silver is reduced, and obtained in a state of purity. Considerable caution is necessary in conducting this experiment. The easiest way of obtaining the silver is, by boiling the chloride in an iron pot with water and pieces of iron. Or we may adopt the process recommended by Gay-Lussac, which consists in putting the chloride into a vessel of zinc or cast-iron, along with a little water. If the vessel be clean the decomposition takes place of itself in a short time, with a considerable increase of tempera-ture. If the zinc or iron be not clean it may be necessary to add a little muriatic or sulphuric acid. These acids are always necessary to wash the reduced silver.†

The chloride of silver is soluble in ammonia. The alkaline carbonates decompose it, but not the pure alkalies; neither is it decomposed by any of the acids. Several of the metals, when fused along with it, separate the silver in its metallic state; but it is always alloyed with a little of the metal employed. Copper, iron, lead, tin, zinc, antimony, and bismuth, have been used for that purpose.‡ If the solution of this salt in ammonia be mixed with running mercury, the silver gradually separates, combines with the mercury, and forms the crystals usually dis-tinguished by the name of *arbor Dianæ.* Margraff recom-mends this amalgamation as the best method of procuring pure silver. This salt dissolves in muriatic acid, and by that means may be obtained in octahedral crystals. When the ammonia-cal solution of this salt is heated, fulminating silver is precipi-tated.§ All substances containing hydrogen have the property of removing the chlorine, but no other bodies.

Considerable pains have been taken to ascertain the consti-tuents of this chloride correctly, because it is by means of it that the different muriates are analyzed. There cannot be a doubt that it is a compound of 1 atom silver and 1 atom chlo-rine. Hence the weight of constituents will depend upon the

* Opusc. i. 265. Proust affirms that this sublimation stops after the salt is in complete fusion.
† Ann. de Chim. et de Phys. xiv. 319.
‡ Margraff, Opusc. i. 265.   § Proust, Nicholson's Journal, xv. 369.

number fixed upon for the atomic weight of silver. I consider it as a compound of

1 atom silver	. .	13·75
1 atom chlorine	. .	4·50
		18·25

While Berzelius would make it

1 atom silver .	.	13·51607
2 atoms chlorine		4·42650
		17·94257

My number is very nearly the mean between the analyses of Dr. Marcet and Gay-Lussac.

IV. When nitrate of silver is dropt into a solution of a hydrobromate the bromide of silver falls down in light yellow curds. When exposed to the light it blackens, but not so readily as chloride of silver. It is insoluble in water, but soluble in ammonia, and insoluble in nitric acid. Boiling sulphuric acid disengages some vapours of bromine from it. When heated it melts into a reddish liquid, which, on cooling, recovers its yellow colour, and assumes the appearance of horn. Nascent hydrogen decomposes it as it does chloride.* From the analysis of this bromide, by Balard and Berzelius, there can be no doubt that it is composed of

Bromide.

1 atom bromine	. .	10
1 atom silver	. . .	13·75
		23·75

V. The iodide of silver is easily obtained by dropping a hydriodate into nitrate of silver. A greenish yellow curdy precipitate falls, having a good deal of resemblance to chloride of silver. It melts at a low red heat, and assumes a reddish colour. When exposed to light its colour is altered more rapidly than even that of chloride of silver. It is insoluble in water, and easily decomposed when heated with potash. It is obvious, from Berzelius's analysis, as well as from analogy, that this iodide is a compound of

Iodide.

1 atom iodine	. .	15·75
1 atom silver	. .	13·75
		29·5

* Balard; Ann. de Chim. et de Phys. xxxii. 361.

VI. No combination of silver with hydrogen, azote, carbon, or boron, is known. When fused with silicon a compound is formed, which leaves behind it a considerable portion of silica when dissolved in nitric acid.*

VII. Silver was first combined with phosphorus by Mr. Pelletier. . If one ounce of silver, one ounce of phosphoric glass, and two drachms of charcoal, be mixed together, and heated in a crucible, *phosphuret of silver* is formed. It is of a white colour, and appears granulated, or as it were crystallized. It breaks under the hammer, but may be cut with a knife. It is composed of 4 parts of silver and 1 of phosphorus. This approaches to

> 1 atom silver   .   .   13·75
> 2 atoms phosphorus   .   4
> _____
> 17·75

but not very nearly. Heat decomposes it by separating the phosphorus.† Pelletier has observed that silver in fusion is capable of combining with more phosphorus than solid silver; for when phosphuret of silver is formed by projecting phosphorus into melted silver, after the crucible is taken from the fire, a quantity of phosphorus is emitted the moment the metal congeals.‡

VIII. When thin plates of silver and sulphur are laid alternately above each other in a crucible, they melt readily in a low red heat, and form *sulphuret of silver*. It is of a black or very deep violet colour; capable of being cut with a knife; often crystallized in small needles; and much more fusible than silver. If sufficient heat be applied, the sulphur is slowly volatilized, and the metal remains behind in a state of purity. This compound frequently occurs native. It has a dark gray colour, a metallic lustre, and the softness, flexibility, and malleability of lead. Its specific gravity is about 7·2. There can be no doubt, from the analysis of Vauquelin, Berzelius, Wenzel, and Klaproth, that this sulphuret is a compound of

> 1 atom sulphur   .   .   2
> 1 atom silver   .   .   13·75
> _____
> 15·75

It is well known that when silver is long exposed to the air,

* Berzelius ; Annals of Philosophy (2d series), x. 120.
† Pelletier ; Ann. de Chim. i. 73.   ‡ Ann. de Chim. xiii. 110.

especially in frequented places, as churches, theatres, &c. it
acquires a covering of a violet colour, which deprives it of its lustre and malleability. This covering, which forms a thin layer, can only be detached from the silver by bending it, or breaking it in pieces with a hammer. It was examined by Mr. Proust, and found to be *sulphuret of silver.* [*]

IX. There is reason to conclude from the experiments of Berzelius, that selenium and silver are capable of combining in two proportions. When the two substances are heated in contact they unite with the evolution of heat, and a very fusible compound is formed, from which the excess of the selenium may be separated by distillation. This seleniet is gray, and while in fusion its surface is brilliant, like a mirror. It melts long before it is heated to redness. It is probably a biseleniet. Part of the selenium may be disengaged by heat, but not the whole. It possesses some malleability.

When silver is precipitated by selenietted hydrogen, it falls in the state of a black powder, which becomes dark gray, when dried. This seleniet requires a red heat to fuse it, and does not give out any selenium when distilled. It is probably a protoseleniet of silver.[†]

X. Gehlen found that when equal parts of silver and arsenic both in powder were heated together, an alloy was formed, composed of 100 silver and 16 arsenic. This approaches 2 atoms silver and 1 atom arsenic. The alloy is steel gray, brittle, and fine granular.

XI. Silver may be alloyed with antimony by fusion. The alloy is brittle, and its specific gravity, as Gellert has observed,[‡] is greater than intermediate between the specific gravities of the two metals which enter into it. There exists native a compound of

5 atoms silver,
3 atoms antimony,

known by the name of antimonial silver ore. Its colour is white, it has the metallic lustre, and a specific gravity of 9·820.

XII. Four parts of silver and two of molybdenum were strongly heated in a crucible, but did not yield a button. By continuing the heat a portion of the silver eliquated, still retaining a part of the molybdenum, and becoming bluish when

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* Ann. de Chim. i. 142.
† Berzelius, Ann. de Chim. et de Phys. x. 245.
‡ Metallurgic Chem. p. 136.

heated.   The residuum being melted again in charcoal, became more compact, was brittle, of a gray colour, and a granular texture.   When melted by itself silver eliquidated.   By nitric acid the silver was taken up from this alloy, and the molybdenum converted into white oxide.

XIII. A hundred parts of silver being mixed with 50 parts of tungstic acid and a quantity of charcoal, and being heated strongly, formed a button of a whitish brown colour, something spongy, which with a few strokes of a hammer extended itself easily, but on continuing them it split in pieces.   This button weighed 142 grains.   This alloy approaches, though not very nearly,

<div align="center">

2 atoms silver,

1 atom tungsten.

</div>

XIV. Serullas did not succeed in forming an alloy of silver and potassium by heating together silver and charred cream of tartar.

XV. Silver and iron, according to Wallerius, unite readily by fusion, and when the quantity of each is equal, the alloy has the colour of silver, but it is harder; it is very ductile, and is attracted by the magnet.[*]   Morveau[†] has shown, that when this alloy is kept in fusion, the metals separate from each other according to their specific gravity, forming two buttons, exceedingly distinct.   Neither of these, however, is in a state of purity.   The silver retains a little iron, which makes it obedient to the magnet.   Coulomb has shown, that the proportion of iron which remains in the silver amounts to $\frac{1}{320}$th part. The iron, on the other hand, retains about $\frac{1}{80}$th of its weight of silver: which gives it an excessive hardness and compactness of structure, of which pure iron is destitute.[‡]   Messrs. Stodart and Faraday fused together 500 parts of very good Indian steel and 1 part of silver, and found the steel very much improved by the addition.   They recommend it as likely to be very useful for making articles of cutlery of very superior quality.[§]

XVI. Silver does not unite with nickel by fusion.

XVII. When 2 parts of cobalt and 1 of silver are melted together, the two metals are obtained separately after the process; the silver at the bottom of the crucible, and the cobalt above it.   Each of them, however, has absorbed a small por-

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[*] Wasserberg, i. 156.   [†] Jour. de Phys. 1788.

[‡] Ann. de Chim. xliii. 47.   [§] Phil. Trans. 1822, p. 256.

tion of the other metal: for the silver is brittle and dark coloured, while the cobalt is whiter than usual.*

XVIII. We are ignorant of the alloys of silver with manganese, cerium, and uranium.

XIX. Silver unites to zinc with facility, and produces a brittle alloy of a bluish white colour, and a granular texture. Its specific gravity, according to Gellert, is greater than the mean. When an alloy of •11 zinc and •1 silver is sublimed in open vessels, the whole of the silver arises along with the flowers of zinc.†

XX. Bismuth combines readily with silver by fusion. The alloy is brittle; its colour is nearly that of bismuth; its texture lamellar; and its specific gravity greater than the mean. According to Muschenbroeck, the specific gravity of an alloy of equal parts bismuth and silver is 10·7097.‡

XXI. Melted lead dissolves a great portion of silver at a slightly red-heat. The alloy is very brittle :§ its colour approaches to that of lead; and, according to Kraft, its specific gravity is greater than the mean density of the two metals united. The tenacity of silver, according to the experiments of Muschenbroeck, is diminished by the addition of lead. This alloy is easily decomposed, and the lead separated by cupellation.

XXII. Silver is easily alloyed with copper by fusion. The compound is harder and more sonorous than silver, and retains its white colour even when the proportion of copper exceeds one-half. The hardness is a maximum when the copper amounts to one-fifth of the silver. The standard or sterling silver of Britain, of which coin is made, is a compound of $12\frac{1}{2}$ silver and one copper. Its specific gravity after simple fusion is 10·200.‖ By calculation it should be 10·351. Hence it follows that the alloy expands, as is the case with gold when united to copper.¶ The specific gravity of Paris standard silver, composed of 137 parts silver and seven copper, according to Brisson, is 10·1752; but by hammering, it becomes as high as 10·3765. The French silver coin, at least during the old government, was not nearly so fine, being composed of 261 parts of silver and 27 of copper, or one part of copper alloyed

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* Gellert, p. 137.   † Wasserberg, i. 160.   ‡ Ibid.
§ Lewis; Neuman's Chem. p. 57.
‖ Cavallo's Nat. Phil. ii. 76.   Dr. Shaw makes it 10·535 after hammering, as it appears from his table.   Shaw's Boyle, ii. 345.
¶ I find the specific gravity of our new silver (1817) 10·3121. The weight of a shilling is 87·55 grains.

with $9\frac{2}{5}$ of silver. Its specific gravity, according to Brisson, was 10·0476; but after being coined, it became as high as 10·4077. The Austrian silver coin, according to Wasserberg, contains $\frac{13}{288}$ of copper.* The silver coin of the ancients was nearly pure, and appears not to have been mixed with alloy. This seems to be the case also with the coins of the East Indies; at least a rupee which I analyzed contained only $\frac{1}{32}$ part of copper; a proportion so small that it can scarcely be supposed to have been added on purpose. A pound of standard silver is coined into 62 shillings.

XXIII. The alloy of silver and tin is very brittle and hard. It was examined by Kraft and Muschenbroeck. According to them, one part of tin and four of silver form a compound as hard as bronze. The addition of more tin softens the alloy. It has a granular appearance, and is easily oxidized. According to Gellert, these metals contract in uniting.† Mr. Hatchet found that silver made standard by tin was brittle, and did not ring well.‡

XXIV. The amalgam of silver is easily formed by throwing pieces of red hot silver into mercury heated till it begins to smoke. It forms dendritical crystals, which, according to the Dijon academicians, contain eight parts of mercury and one of silver. It is of a white colour, and is always of a soft consist-

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* Wasserberg, i. 155. The following table exhibits the composition of different European coins, according to my experiments.

	Alloy per cent.		Weight of silver, that of the copper being 1.
British	7·5		12·5
Dutch	8		11·5
French	9		10·1
Austrian	9·5		9·5
Sardinian	95		9·5
Spanish	{ 10·5		8·5
	{ 15·5		5·5
Portuguese	11		8
Danish	1£		7·3
Swiss	21		3·8
Russian	24		3·6
Hamburgh	50		1

The first column of this table gives the supposed proportion of alloy in 100 parts of the respective coin; the second gives the weight of silver contained in each coin, on the supposition that the weight of the copper with which the silver is alloyed is always 1. Nicholson's Jour. xiv. 409. The reader will find the analysis of a number of ancient Roman silver coins in the Ann. de Chim. et de Phys. xxxii. 320.

† Metallurgic Chem. p. 140.   ‡ On the Alloys of Gold, p. 33.

ence. Its specific gravity is greater than the mean of the two metals. Gellert has even remarked, that when thrown into pure mercury, it sinks to the bottom of that liquid.* When heated sufficiently, the mercury is volatilized, and the silver remains behind pure. This amalgam is sometimes employed, like that of gold, to cover the surfaces of the inferior metals with a thin coat of silver. Two different amalgams of silver have been found native; but they are both exceedingly rare minerals. One of these *native amalgams*, as they are called, is composed of

1 atom silver	.	13·75
2 atoms mercury	. .	25
		———
	.	38·75

and the other of

1 atom silver	. .	13·75
3 atoms mercury	. .	37·5
		———
		51·25

The affinity between silver and mercury is very considerable.

FAMILY V. NOBLE BASES.

I have given this name for want of a better to gold, platinum, and four metals which usually accompany platinum in those parts of the earth where it is found. They possess so many common properties that it is most convenient to consider them together. The oxides of these metals are easily reduced to the metallic state by heat, if we except the oxide of osmium, which is too volatile to bear the application of heat. The greater number of them show but little inclination to unite with acids or to form salts.

SECTION I.—OF GOLD.

Gold seems to have been known from the very beginning of the world. Its properties and its scarcity have rendered it more valuable than any other metal.†

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* Gellert's Metallurgic Chemistry, 142.

† The fullest treatise on gold hitherto published is that by Dr. Lewis in his Philosophical Commerce of the Arts. The account of gold in Wasserberg's Institutiones Chemiæ, vol. i. is, a great part of it at least, nearly a translation of Dr. Lewis; but it contains likewise several discoveries of posterior date, chiefly made by Bergman. Mr. Hatchett's Experiments and Ob-

It is of an orange-red, or reddish-yellow colour, and has no perceptible taste or smell. Its lustre is considerable, yielding only to that of platinum, steel, silver, and mercury. It is rather softer than silver. Its specific gravity is 19·3.* No other substance is equal to it in ductility and malleability. It may be beaten out into leaves so thin, that one grain of gold will cover $56\frac{3}{4}$ square inches. These leaves are only $\frac{1}{282000}$ of an inch thick. But the gold leaf with which silver wire is covered has only $\frac{1}{12}$ of that thickness. An ounce of gold upon silver wire is capable of being extended more than 1300 miles in length.†

Its tenacity is considerable; though in this respect it yields to iron, copper, platinum, and silver. From the experiments of Sickingen, it appears that a gold wire 0·078 inch in diameter is capable of supporting a weight of 150·07 lbs. avoirdupois, without breaking.‡

It melts at 32° of Wedgewood's pyrometer,§ or at 2590° Fahrenheit, according to Davies. When melted, it assumes a bright bluish-green colour. It expands in the act of fusion, and consequently contracts while becoming solid more than most metals; a circumstance which renders it less proper for casting into moulds.‖ It requires a very violent heat to volatilize it; it is therefore, to use a chemical term, exceedingly *fixed*. Gasto Claveus informs us that he put an ounce of pure gold in

servations on the Alloys, Specific Gravity, and Comparative Wear of Gold, published in the Phil. Trans. for 1803, are of the utmost importance, on account of the care with which they were made, and the many mistaken notions which they have enabled us to rectify. Proust published a valuable paper on gold in the Journal de Physique. It was afterwards examined by Vauquelin (Ann. de Chim. lxxvii. 321); Oberkamp, (Ibid. lxxx. 140); Berzelius, (Ibid. lxxxiii. 166); Pelletier and Laval.

* The specific gravity of gold varies somewhat according to its state, that being heaviest which has been hammered or rolled. Dr. Lewis informs us that he found, on many different trials, the specific gravity of pure gold, well hammered, between 19·300 and 19·400. The specific gravity of one mass which he specifies was 19·376, (Philosophical Commerce of the Arts, p. 41). Brisson found the specific gravity of another specimen of fine gold, hammered, 19·361. Mr. Hatchett tried gold of 23 carats 3¾ grains, (or gold containing 1-96th of alloy); its specific gravity was 19·277.

† See Shaw's Boyle, i. 404, and Lewis's Phil. Commerce of the Arts, p. 44.

‡ Ann. de Chim. xxv. 9.

§ According to the calculation of the Dijon academicians, it melts at 1298° Fahrenheit; according to Mortimer, at 1301°.

‖ Lewis's Philosophical Commerce, p. 67.

an earthen vessel, into that part of a glass-house furnace where
the glass is kept constantly melted, and kept it in a state of
fusion for two months, yet it did not lose the smallest portion
of its weight.* Kunkel relates a similar experiment attended
with the same result;† neither did gold lose any perceptible
weight, after being exposed for some hours to the utmost heat
of Mr. Parker's lens.‡ Homberg, however, observed, that
when a very small portion of gold is kept in a violent heat, part
of it is volatilized.§ This observation was confirmed by Mac-
quer, who observed the metal rising in fumes to the height of
five or six inches, and attaching itself to a plate of silver, which
it gilded very sensibly;‖ and Mr. Lavoisier observed the very
same thing when a piece of silver was held over gold melted
by a fire blown by oxygen gas, which produces a much greater
heat than common air.¶ After fusion, it is capable of assuming
a crystalline form. Tillet and Mongez obtained it in short
quadrangular pyramidal crystals. Gold is not in the least
altered by being kept exposed to the air; it does not even lose
its lustre. Neither has water the smallest action upon it.

II. It is capable, however, of combining with oxygen, and **Oxides.**
even of undergoing combustion in particular circumstances.
The resulting compound is an *oxide of gold.* Gold must be
raised to a very high temperature before it is capable of abstract-
ing oxygen from common air. It may be kept red-hot almost
any length of time without any such change. Homberg, how-
ever, observed, that when placed in the focus of Tschirnhaus's
burning-glass, a little of it was converted into a purple-coloured
oxide; and the truth of his observations was confirmed by the
subsequent experiments of Macquer with the very same burn-
ing-glass.** But the portion of oxide formed in these trials is
too small to admit of being examined. Electricity furnishes a
method of oxidizing it in greater quantity.

If a narrow slip of gold leaf be put, with both ends hanging
out a little, between two glass plates tied together, and a strong
electrical explosion be passed through it, the gold leaf is miss-
ing in several places, and the glass is tinged of a purple colour

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* " Nec minimum de pondere decidisse conspexi." Gastonis Clavei Apo-
logia Argyropoeiæ et Chrysopoeæ adversus Thomam Erastum, Theatrum
Chemicum, ii. 17.
† Lewis, Philosophical Commerce, p. 70.
‡ Kirwan's Mineralogy, i. 92.   § Mem. Par. 1702, p. 147.
‖ Dictionnaire de Chimie, ii. 148.   ¶ Kirwan's Min. ii. 92.
** Dict. ii. 153.

by the portion of the metal which has been oxidized? This curious experiment was first made by Dr. Franklin;* it was confirmed in 1773 by Camus. The reality of the oxidizement of gold by electricity was disputed by some philosophers, but it has been put beyond the reach of doubt by the experiments of Van Marum. When he made electric sparks from the powerful Teylerian machine pass through a gold wire suspended in the air, it took fire, burnt with a green-coloured flame, and was completely dissipated in fumes, which, when collected, proved to be a purple coloured oxide of gold. This combustion, according to Van Marum, succeeded not only in common air, but also when the wire was suspended in hydrogen gas, and other gases which are not capable of supporting combustion. The combustion of gold is now easily effected by exposing gold-leaf to the action of the galvanic battery. I have made it burn with great brilliancy, and a green-coloured flame, by exposing a gold wire to the action of a stream of oxygen and hydrogen gas mixed together and burning. Now, in all cases of combustion, the gold is oxidized. We are acquainted only with two oxides of gold. The *protoxide* has a *green* colour, the *peroxide* is *reddish-brown.*

1. Of these the *peroxide* is most easily procured; it is, therefore, best known. It may be procured in the following manner: 1 part of nitric and 4 of muriatic acid are mixed together, and poured upon gold: an effervescence takes place, the gold is gradually dissolved, and the liquid assumes a yellow colour. Let this solution be rendered as neutral as possible by cautiously evaporating it to dryness and re-dissolving it in water. Into the solution pour a quantity of potash, and then heat the liquid. A voluminous precipitate gradually appears. It must be carefully washed with water and dried. Pelletier assures us that when the oxide is made in this way it is never free from potash. He recommends the following process as yielding pure oxide: To the neutral solution of gold in aqua regia, add caustic magnesia till there be a small excess of it. A precipitate falls consisting of the oxide of gold united to magnesia, and a small portion of the gold still remains in solution. Wash the precipitate thoroughly, then digest it in nitric acid, which will dissolve the magnesia, together with a small portion of the gold, and leave the oxide of gold in a state of purity. If the nitric acid used was dilute, we obtain the gold in the state of a

* Lewis's Philosoph. Commerce, p. 175. This work was published in 1763.

light yellow oxide, or rather *hydrate;* but if the acid was concentrated, the oxide is black or dark brown, and anhydrous. When the hydrated oxide is exposed to a heat of 212° it loses its water, and is partly reduced to the metallic state. It dissolves completely in muriatic acid, and the solution has a fine yellow colour. At an incipient red heat, it is completely reduced to the metallic state.

I have shown that when 25 grains of gold are dissolved in nitromuriatic acid, and the solution rendered as neutral as possible, if we add to the solution 27 grains of protoxide of iron, the whole gold is thrown down in the metallic state, and the protoxide of iron is converted into peroxide, and therefore has combined with 3 of oxygen.* It follows from this that the yellow oxide of gold is a compound of

Gold	.	.	25
Oxygen	.	.	3
			28

Now as 3 denoting the quantity of oxygen is a whole number, it is clear that 25 or some multiple or submultiple of it is the atomic weight of gold. To discover what the true number is, we may have recourse to the law discovered by Dulong and Petit, namely, that the atomic weight of a body is obtained when we divide the number 0·376 by the specific heat of that body. The

specific gravity of gold is 0·03, and $\dfrac{0·376}{0·03} = 12·53$. It is evi-

dent from this that the atom of gold is 12·5. Consequently the oxide of gold is a compound of

$1\frac{1}{2}$ atom oxygen	.	.	1·5
1 atom gold	.	.	12·5
			14

and its atomic weight is 14.

2. When the chloride of gold is heated till it ceases to give out chlorine gas, a straw-yellow mass remains, which is insoluble in cold water. When this substance is treated with caustic potash a green-coloured powder is separated, which is *suboxide of gold.* In a short time this oxide divides itself into two parts. One-third deprives the other two-thirds of the whole of their oxygen and becomes peroxide, while the two-thirds are reduced to the metallic state.† From this it is obvious that the sub-

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* Edin. Phil. Trans. ii. 26.   † Berzelius, Ann. de Chim. lxxxiii. 166.

oxide of gold contains only one-third of the oxygen which exists in 'the peroxide.   It is therefore a compound of

1 atom oxygen	. .	1
2 atoms gold	. .	25
		—
		26

This suboxide does not seem capable of uniting either with acids or bases.

3. It has been supposed that the oxide of gold formed by electricity or by the combustion of gold, is intermediate between the suboxide and peroxide. 'If this opinion be well founded, the purple oxide must be a' compound of

1 atom oxygen	. .	1
1 atom gold	. .	12·5
		—
		13·5

But 'no satisfactory evidence has been adduced to prove the truth of this opinion.

It has been supposed that the beautiful colour of the purple of Cassius is owing to the presence of this oxide.   But the observations of Proust, together with those of Marcadieu,[*] seem to leave no doubt that the gold in this beautiful powder is in the metallic state.   Purple of Cassius is obtained by dropping a solution of gold into a solution containing both the oxides of tin.   When dropt into a solution of protomuriate of tin, it is a dark brown without any beauty.   We must have both' oxides in the solution to ensure the fine purple of Cassius.

III. When gold-leaf is exposed to the action of chlorine gas, a combination takes place ; but the gold does not burn. When gold is dissolved in aqua regia, and the solution sufficiently concentrated by evaporation, beautiful ruby red crystals shoot; but they are so deliquescent that it is very difficult to preserve them.   The taste is astringent and very disagreeable, and it acts when taken internally as a virulent poison.   These crystals (abstracting the water) are composed, according to the analysis of Berzelius, of

1½ atom chlorine	. .	6·75
1 atom gold	. .	12·5
		—
		19·25

[*] Ann. de Chim. et de Phys. xxxiv. 147.

1. When the solution of gold in aqua regia is cautiously evaporated till the colour becomes brown, it becomes a solid mass on cooling, and a portion of the gold is disengaged from its combination. By this evaporation the gold is converted into a chloride composed of

1 atom chlorine	. .	4·5
1 atom gold	. .	12·5
		17·0

as I ascertained by a very carefully conducted analysis.*

2. Berzelius informs us that when the crystals of sesquichloride of gold are fused and sufficiently heated, they may be converted into a subchloride of gold, composed of

1 atom chlorine	. . . .	4·5
2 atoms gold	. .	25
		29·5

I did not succeed in obtaining this subchloride; but from the analogy of the suboxide its existence is very probable.

The sesquichloride of gold possesses the characters of an acid. Those salts which have been described under the names of double chlorides of gold, are in reality salts in which the sesquichloride of gold acts the part of an acid, and the other chloride that of a base. These chlorine salts will come under our review in a subsequent part of this work.

IV. Bromine and its aqueous solution are capable of dissolv- Bromide. ing gold. By this means a yellow bromide is obtained which stains animal bodies purple, as is the case with the chlorides of this metal. Heat decomposes it into bromine and metallic gold.†

V. Iodide of gold may be obtained by mixing together Iodide. chloride of gold and hydriodate of potash, taking care to heat the liquid in order to drive off the excess of iodine which precipitates with the iodide of gold. This iodide is insoluble in cold water, and but little soluble in boiling water. Muriatic, nitric, and sulphuric acids, do not decompose it cold, but when it is boiled in these acids in a concentrated state, the gold is

* Edin. Phil. Trans. ii. 27. Professor Berzelius and Mr. Johnstone have thought proper to call in question the accuracy of this analysis in no very measured terms; because they analyzed the *sesquichloride* of gold, and obtained a different result. I have only to mention that both of these chlorides exist, as I have ascertained by actual experiment. Nothing can be conceived more illogical than to infer that an analysis of a salt is wrong, because the analysis of a different salt does not agree with it.

† Balard, Ann. de Chim. et de Phys. xxxii. 362.

reduced and the iodine disengaged. Heat decomposes it at a temperature not higher than 300°. Alkaline solutions decompose it immediately. With potash we obtain iodate and hydriodate of potash, and the gold remains in the state of a yellow powder. According to the analysis of M. Pelletier, the discoverer of iodide of gold, and to whom we are indebted for all the facts which I have stated respecting it, this iodide is a compound of 34 of iodine and 66 of gold. This, if we make allowance for a little water, which in all probability the iodine still retained, is equivalent to

1 atom iodine	15·75
3 atoms gold	37·5
	———
	53·25*

Neither the oxides nor chlorides of gold have exhibited any compound analogous to this which is a trisiodide.

VI. Nothing is known respecting the compounds which gold may be capable of forming with hydrogen, azote, carbon, boron, or silicon.

Phosphuret. VII. Margraff failed in his attempts to unite gold with phosphorus;[†] but Pelletier was fortunate enough to succeed by melting together in a crucible half an ounce of gold and an ounce of phosphoric glass,[‡] surrounded with charcoal. The *phosphuret of gold* thus produced was brittle, whiter than gold, and had a crystallized appearance. It was composed of 23 parts of gold and one of phosphorus,[§] or of 1 atom phosphorus and 4 atoms gold. He formed the same compound by dropping small pieces of phosphorus into gold in fusion.[||] By the application of a sufficient heat, the phosphorus is dissipated and the gold remains. Oberkampf formed phosphuret of gold by precipitating chloride of gold by means of water impregnated with phosphuretted hydrogen gas.

Sulphuret. VIII. Sulphur, even when assisted by heat, has no action on gold whatever; nor is it ever found naturally combined with sulphur, as is the case with most of the other metals; yet it can scarcely be doubted that sulphur exercises some action on gold, though but a small one; for when an *alkaline hydro-sulphuret*[¶] is dropped into a solution of gold, a *black powder* falls

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* Ann. de Chim. et de Phys. xv. 116.   † Opusc. i. 2.
‡ Phosphoric acid evaporated to dryness, and then fused.
§ Ann. de Chim. i. 71. || Ibid. xiii. 104.
¶ By this is understood a combination of sulphuretted hydrogen and an alkali.

to the bottom, which is found to consist of gold and sulphur;
and when potash, sulphur, and gold, are heated together, and
the mixture boiled in water, a considerable portion of gold is
dissolved, as Stahl first discovered. Three parts of sulphur,
and three of potash, are sufficient to dissolve one of gold. The
solution has a yellow colour. When an acid is dropped into
it, the gold falls down, united to the sulphur in the state of a
reddish powder, which becomes gradually black.* The com-
position of this sulphuret has been investigated by Bucholz†
and Oberkampf.‡ The following are the results which they
obtained:

	Bucholz.			Oberkampf.
Gold	100	.	.	100
Sulphur	21·95	.	.	24·39

If we consider Oberkampf's analysis as correct, this compound
consists of

1½ atom sulphur	. .	3
1 atom gold	. .	12·5
		———
		15·5

It is therefore analogous to the common oxide and chloride of
gold.

IX. There appears to be a strong affinity between gold and
arsenic: but in consequence of the great volatility of the latter
metal, it is difficult to unite them by fusion. Bergman suc-
ceeded in making gold take up $\frac{1}{60}$th of its weight of arsenic.§
Mr. Hatchett added 453 grains of arsenic to 5307 grains of
melted gold, and, stirring the whole rapidly with an iron rod,
poured the mixture into an iron mould. Only six grains of
the arsenic were retained; so that the alloy contained only
$\frac{1}{885}$th of arsenic. It had the colour of fine gold; and though
brittle, yet it bent in some measure before it broke. When
once united to gold, arsenic is not easily expelled by heat. Mr.
Hatchett discovered that gold readily imbibes, and combines
with, arsenic, when heated to redness. A plate of gold was
exposed red-hot to the fumes of arsenic by suspending it near
the top of a dome, made by luting one crucible inverted over
another. In the lower crucible some arsenic was put, and the
whole exposed to a common fire for about 15 minutes. The
arsenic had acted on the gold, and combined with its surface.

Arseniet.

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* Stahl's Opusc. Chym.-Phys.-Med. p. 606. † Beitrage, iii. 171.
‡ Ann. de Chim. lxxx. 144. § Opusc. ii. 281.

The alloy being very fusible had dropped off as it formed, leaving the gold thinner, but quite smooth.   The alloy of gold and arsenic formed a button in the undermost crucible.   This button had a gray colour, and was extremely brittle.*

Antimoniet.   X. Antimony and gold may be combined by fusion, and form a brittle compound of a yellow colour.   Great attention was paid to this alloy by the alchymists, who affirmed, that the quantity of gold might be increased by alloying it with antimony and then purifying it.†

Gold made standard by antimony, in Mr. Hatchett's experiments, was of a dull pale colour, not unlike tutenag.   It was exceedingly brittle, and in the fracture was of an ash-colour, with a fine close grain, not unlike that of porcelain. Its specific gravity was 16·929.   The bulk of the two metals before fusion being 1000, after fusion it was 987.   Hence they suffer a considerable contraction.   A very small proportion of antimony destroys the ductility of gold : the alloy was perfectly brittle when the antimony did not exceed $\frac{1}{1920}$ part of the mass.   Even the fumes of antimony in the neighbourhood of melted gold, are sufficient to destroy its ductility.‡

Alloys with   XI. Potassium and sodium may readily be combined with gold by heat, as Davy ascertained.   The alloys are destroyed in the open air, or when put into water.

XII. We are not acquainted with the action of gold on the metallic bases of the alkaline earths or earths proper.

Iron,   XIII. Iron unites very readily with gold by fusion in all its states of soft iron, cast-iron, and steel.   The alloy was examined by Mr. Hatchett, who found it remarkably ductile when composed of 11 gold and 1 iron.   It was easily rolled into plates, cut into blocks, and stamped into coin, without its being necessary to anneal it.   The colour was a pale yellowish gray approaching to a dull white ; its specific gravity was 16·885.   The bulk of the metals before fusion was 2799 ; after their union the bulk was 2843.   Hence they suffer an expansion, as had been previously noticed by Gellert.   Suppose the bulk before union to have been 1000, after union it becomes 1014·7.§   This alloy is harder than gold.   Dr. Lewis even says that it is fit for making edge-tools ; but in that case the proportion of iron was doubt-

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* On the Alloys of Gold, p. 7.

† This made them give antimony the name of *balneum regale*.   The cause of their mistake is obvious ; they did not separate the whole of the antimony from the gold ; hence the increase of weight.

‡ Hatchett on the Alloys of Gold, p. 13.   § Ibid. p. 37.

less increased. When the iron is three or four times the quantity of gold, the alloy, according to Dr. Lewis, has the colour of silver :* according to Wallerius it still continued magnetic.† . Gold answers well as a solder for iron.

XIV. Mr. Hatchett melted a mixture of 11 gold and 1 nickel, and obtained an alloy of the colour of fine brass. It was brittle, and broke with a coarse-grained earthy fracture. The specific gravity of the gold was 19·172 ; of the nickel 7·8; that of the alloy 17·068. The bulk of the metals before fusion was 2792, after fusion 2812. Hence they suffered an expansion. Had their bulk before fusion been 1000, after fusion it would have become 1007. When the proportion of nickel is diminished, and copper substituted for it, the brittleness of the alloy gradually diminishes, and its colour approaches to that of gold. The expansion, as was to be expected, increases with the proportion of copper introduced.‡   *Nickel,*

XV. Mr. Hatchett melted together 14 parts of gold and 1 part of cobalt. The alloy was of a dull yellow colour, very brittle, and the fracture exhibited an earthy grain. Its specific gravity was 17·112. The bulk of the metals before fusion being 1000, after fusion, became 1001. Hence they experienced a very small degree of expansion. The brittleness of gold alloyed with cobalt continues when the cobalt does not exceed $\frac{1}{60}$th of the whole; but when it is reduced below that proportion, the gold becomes somewhat ductile.§   *Cobalt,*

XVI. We are indebted to Mr. Hatchett for some curious experiments on the alloy of manganese and gold. Olive oil was repeatedly mixed and burned with black oxide of manganese, after which a piece of gold was imbedded in the oxide, placed in a crucible lined with charcoal, and well luted. The crucible was exposed for three hours to a strong heat. By this means a portion of manganese was reduced and combined with the gold. The alloy was externally of a pale yellowish-gray colour, with a considerable lustre, almost equal to that of polished steel. It was very hard, and possessed some ductility. The fracture was coarse, very spongy, and of a reddish-gray colour. It was not altered by exposure to the air. From the analysis of Mr. Bingley, the alloy was found to vary in the proportion of manganese from $\frac{1}{8}$th to $\frac{1}{9}$th of the whole. It is more difficult of fusion than gold. When kept melted with access of air, the   *Manganese,*

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* Phil. Com. p. 85.   † Wasserberg, i. 115.
‡ Hatchett on the Alloys of Gold, p. 21.   § Ibid. p. 19.

whole manganese is oxidized, and swims on the surface. „ The manganese may be separated by cupellation with lead.*

XVII. The alloys of gold with uranium and cerium are unknown.

Zinc,

XVIII. Zinc may be united to gold in any proportion by fusion. The alloy is the whiter and the more brittle the greater quantity of zinc it contains. An alloy, consisting of equal parts of these metals, is very hard and white, receives a fine polish, and does not tarnish readily. It has, therefore, been proposed by Mr. Hellot† as very proper for the specula of telescopes. Mr. Hatchett united 11 parts of gold and 1 of zinc. The alloy was of a pale greenish-yellow like brass, and very brittle. Its specific gravity was 16·937. The bulk of the metals before union was 1000; after it, 997 nearly. Hence the union is accompanied with a small degree of contraction. The brittleness continued though the zinc was reduced to $\frac{1}{60}$th of the alloy, $\frac{4}{60}$ths of copper being added to reduce the gold to the standard value. Even the fumes of zinc near melted gold are sufficient to render the precious metal brittle.‡ Hellot affirms, that when 1 part of gold is alloyed with 7 of zinc, if the zinc be elevated in the state of flowers, the whole of the gold rises along with it.

Bismuth,

XIX. Gold combines very readily with bismuth by fusion. An alloy composed of 11 gold and 1 bismuth was found by Hatchett to have a greenish-yellow colour, like bad brass. It was very brittle, and had a fine grained earthy fracture. Its specific gravity was 18·038. The bulk of the metals before fusion was 1000, after it only 988. They had suffered, therefore, a considerable contraction. The properties of the alloy continued nearly the same when the bismuth amounted to $\frac{1}{60}$th of the compound; the requisite quantity of copper to reduce the gold to standard being added. When the bismuth was diminished beyond this proportion, the colour of the alloy became nearly that of gold; but its brittleness continued even when the bismuth did not exceed $\frac{1}{1900}$th of the mass. As the proportion of bismuth diminished, and that of the copper increased (the gold being always standard), the contraction disappeared, and an expansion took place, which was soon much greater than when copper alone was used to alloy the gold. This curious progression will appear evident from the following table.§

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* Hatchett on the Alloys of Gold, p. 22.　　† Mem. Acad. Par. 1735.
‡ Hatchett on the Alloys of Gold, p. 17.
§ The specific gravity of the gold was 19·172 (it was 23 carats 8¼ grains fine), of the bismuth 9·822, of the copper 8·895.

Metals.	Grains.	Specific gravity of alloy.	Bulk before fusion.	Do. after.	Change of bulk.
Gold . . Bismuth .	442 38	18·038	1000	988	—12
Gold . . Copper . Bismuth .	442 30 8	17·302	1000	1018	+18
Gold . . Copper . Bismuth .	442 34 4	16·846	1000	1044	+44
Gold . . Copper . Bismuth .	442 37·5 0·5	16·780	1000	1047	+47
Gold . . Copper . Bismuth .	442 37·75 0·25	17·495	1000	1027	+27

So great is the tendency of bismuth to give brittleness to gold, that the precious metal is deprived of its ductility, merely by keeping it, while in fusion, near bismuth raised to the same temperature.*

XX. When 11 parts of gold are melted with one of lead, an Lead, alloy is formed, which has externally the colour of gold, but is rather more pale. It is exceedingly brittle, breaking like glass, and exhibiting a fine-grained fracture, of a pale brown colour, without any metallic lustre, and having the appearance of porcelain. The brittleness continues even when the proportion of lead is so far diminished that it amounts only to $\frac{1}{1920}$th of the alloy. Even the fumes of lead are sufficient to destroy the ductility of gold. The specific gravity of the alloy of 11 gold and 1 lead is 18·080, which is somewhat less than the mean; so that the metals undergo an expansion. This expansion increases as the lead diminishes (the gold remaining the same), and the deficiency being supplied by copper, and becomes a maximum when the lead amounts only to $\frac{1}{960}$th of the alloy. The following table exhibits a view of this remarkable expansion:

* See Hatchett on the Alloys of Gold, p. 26.

Metals.	Grains.	Specific gravity of alloy.	Bulk before union.	Do. after.	Expansion.
Gold . Lead .	442 38	18·080	1000	1005	5
Gold . Lead . Copper	442 19 19	17·765	1000	1005	6
Gold . Copper Lead .	442 30 8	17·312	1000	1022	22
Gold .. Copper Lead .	442 34 4	17·032	1000	1035	35
Gold . Copper Lead .	442 37·5 0·5	16·627	1000	1057	57
Gold . Copper Lead .	442 37·75 0·25	17·039	1000	1031	31*

Tin,   XXI. Tin unites readily with gold by fusion, and was supposed by the older chemists to have the property of communicating brittleness to the alloy in how small a portion soever it was united to the precious metal; but later and more precise experiments have shown that this opinion was ill founded. The mistake was first removed by Mr. Alchorne, in a set of experiments on this alloy published in the Philosophical Transactions for 1784; and these have been amply confirmed by the subsequent trials of Mr. Hatchett. An alloy of 11 gold and 1 tin has a very pale whitish colour; brittle when thick; but when cast thin, it bends easily, but breaks when passed between rollers. The fracture is fine grained, and has an earthy appearance. The specific gravity of this alloy was 17·307. The bulk of the two metals before fusion being reckoned 1000, after fusion, it was reduced to 981; so that the metals contract very considerably by uniting together.† When gold was made

* See Hatchett on the Alloys of Gold, pp. 29 and 67.
† Ibid. p. 32.

standard by equal parts of tin and copper, an alloy was obtained of a pale yellow colour, and brittle; but when the tin amounted only to $\frac{1}{60}$th of the whole, the alloy was perfectly ductile.* Indeed, from the experiments of Mr. Alchorne, we learn, that when gold is alloyed with no more than $\frac{1}{37}$th of tin, it retains its ductility sufficiently to be rolled and stamped in the usual way. But Mr. Tillet showed, as was indeed to have been expected, that when heated to redness, it falls to pieces, owing to the fusion of the tin. Both of these facts have been confirmed by the late experiments of Mr. Bingley. He found that an alloy of gold with $\frac{1}{60}$th of tin, when annealed in a red heat, just visible by daylight, which is equal to 5° of Wedgewood, was quite ductile, and capable of being worked into any form; but when heated to a cherry red, or to 10° Wedgewood, blisters began to appear on the surface of the bar: its edges curled up; and at last it lost its continuity, and fell into a dark-coloured mass with little of the metallic lustre.†

XXII. The alloy of gold and copper is easily formed by Copper, melting the two metals together. This alloy is much used, because copper has the property of increasing the hardness of gold without injuring its colour. Indeed a little copper heightens the colour of gold without diminishing its ductility. This alloy is more fusible than gold, and is therefore used as a solder for that precious metal.‡ Copper increases likewise the hardness of gold. According to Muschenbroeck, the hardness of this alloy is a maximum when it is composed of 7 parts of gold and 1 of copper.§ Gold alloyed with $\frac{1}{22}$ of pure copper by Mr. Hatchett, was perfectly ductile, and of a fine yellow colour, inclining to red. Its specific gravity was 17·157. This was below the mean. Hence the metals had suffered an expansion. Their bulk before union was 2732, after union 2798. So that $916\frac{2}{3}$ of gold and $83\frac{1}{3}$ of copper when united, instead of occupying the space of 1000, as would happen were there no expansion, become 1024.||

Gold coin, sterling or standard gold, consists of pure gold

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* Hatchett, on the Alloys of Gold, p. 32.   † Ibid.
‡ Wassenberg, i. 112.   § Ibid.
|| Hatchett on the Alloys of Gold, p. 66. The gold was already alloyed with 1-96th of copper; the expansion, had the gold been pure, would have been greater. For the specific gravity of an alloy of 11 gold and 1 copper, (supposing the specific gravity of gold 19·3, and of copper 8·9), should be by calculation 17·58. Its real specific gravity is only 17·157.

alloyed with $\frac{1}{12}$th of some other metal. The metal used is always either copper or silver, or a mixture of both, as is most common in British coin. Now it appears that when gold is made standard by a mixture of equal weights of silver and copper, the expansion is greater than when the copper alone is used, though the specific gravity of gold alloyed with silver differs but little from the mean. The specific gravity of gold alloyed with $\frac{1}{24}$th of silver and $\frac{1}{24}$th of copper was 17·344. The bulk of the metals before combination was 2700; after it 2767.* We learn from the experiments of Mr. Hatchett that our standard gold suffers less from friction than pure gold, or gold made standard by any other metal besides silver and

* The first guineas coined were made standard by silver, afterwards copper was added to make up for the deficiency of the alloy; and as the proportion of the silver and copper varies, the specific gravity of our gold coin is various also.

The specific gravity of gold made standard by silver is   .   17·927

                      copper   .   17·157

                      silver and copper   17·344

The following trials made by Mr. Hatchett will show the specific gravity of our coins in different reigns.

Reign.					Date.	Specific gravity.
CHARLES II.	a five guinea piece	.	.	.	1681	17·825
JAMES II.	a two guinea piece	.	.	.	1687	17·634
WILLIAM III.	a five guinea piece	.	.	.	1701	17·710
GEORGE I.	a quarter guinea	.	.	.	1718	16.894
GEORGE II.	a guinea	.	.	.	1735	17·637
——————	a two guinea piece	.	.	.	1740	17·848
GEORGE III.	a one guinea	.	.	.	1761	17·737
——————	a one guinea	.	.	.	1766	17·655
——————	a one guinea	.	.	.	1774	17·726
——————	a one guinea	.	.	.	1775	17·698
——————	a one guinea	.	.	.	1776	17.486
——————	a one guinea	.	.	.	1777	17·750
——————	a one guinea	.	.	.	1782	17·202
——————	a one guinea	.	.	.	1786	17·465
——————	a one guinea	.	.	.	1788	17·418
——————	five guineas	.	.	.	1793	17·712
——————	ten half guineas	.	.	.	1801	17·750
——————	fifteen seven-shilling pieces[1]		.		1802	17·793

[1] Supposing guineas, half-guineas, and seven-shilling pieces, to be made from the same metal, there is reason to expect (in a given comparative sum of each) an increase of specific gravity in the smaller coins, as a natural consequence of rolling, punching, annealing, blanching, milling, and stamping; the effects of which must become more evident in proportion to the number of the small pieces required to form a given sum of the larger coins.

The average specific gravity of our gold coin, at the present time, may probably be estimated at 17·724.

copper; and that the stamp is not so liable to be obliterated
as in pure gold. It therefore answers better for coin. A
pound of standard gold is coined into 44½ guineas,

XXIII. The amalgam of gold is formed very readily, because
there is a very strong affinity between the two metals. If a bit
of gold be dipped into mercury, its surface, by combining
with mercury, becomes as white as silver. The easiest way of
forming this amalgam is to throw small pieces of red-hot gold
into mercury heated till it begins to smoke. The proportions
of the ingredients are not determinable, because they combine
in any proportion. This amalgam is of a silvery whiteness.
By squeezing it through leather, the excess of mercury may
be separated, and a soft white amalgam obtained, which gra-
dually becomes solid, and consists of about 1 part of mercury
to 2 of gold. It melts at a moderate temperature; and in a
heat below redness the mercury evaporates, and leaves the
gold in a state of purity. It is much used in gilding. The
amalgam is spread upon the metal, which is to be gilt; and
then by the application of a gentle and equal heat, the mer-
cury is driven off, and the gold left adhering to the metallic
surface; this surface is then rubbed with a brass wire brush
under water, and afterwards burnished.*

XXIV. When silver and gold are kept melted together,
they combine, and form an alloy, composed, as Homberg ascer-
tained, of 1 part of silver and 5 of gold. He kept equal parts
of gold and silver in gentle fusion for a quarter of an hour,
and found, on breaking the crucible, two masses, the upper-
most of which was pure silver, the undermost the whole gold
combined with $\frac{1}{6}$ of silver. Silver, however, may be melted with
gold in almost any proportion; and if the proper precautions
be employed, the two metals remain combined together.

The alloy of gold and silver is harder and more sonorous
than gold. Its hardness is a maximum when the alloy con-
tains 2 parts of gold and 1 of silver.† The density of these
metals is a little diminished,‡ and the colour of the gold is
much altered, even when the proportion of the silver is small;
1 part of silver produces a sensible whiteness in 20 parts of
gold. The colour is not only pale, but it has also a very sen-
sible greenish tinge, as if the light reflected by the silver passed
through a very thin covering of gold. This alloy being more

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* Gellert's Metallurgic Chemistry, 375, and Lewis, Phil. Com. p. 75.
† Muschenbroeck.   ‡ Hatchett.

fusible than gold, is employed to solder pieces of that metal together.

XXV. With gold molybdenum melts only imperfectly, and forms a blackish brittle mass, from which a considerable portion of the °gold eliquates when it is kept in a strong heat. The alloy is attacked by nitric acid. The gold subsides in the state of a fine powder, and the molybdenum lies over it in the form of white oxide. The proportions tried were

Gold	. .	6, 4, 2.
Molybdenum	.	2, 2, 2.

None of these compounds could be brought into perfect fusion even by the assistance of borax.*

XXVI. When 100 parts of gold, 50 parts of tungstic acid, and a quantity of charcoal powder, were strongly heated in a covered crucible, complete fusion did not take place. The button weighed 139 grains. By cupellation with lead the gold was reduced to its original purity. With platinum it refused likewise to melt. The mass obtained weighed 140 grains.

SECTION II.—OF PLATINUM.

History.

Gold, the metal just described, was known in the earliest ages, and has been always in high estimation, on account of its scarcity, beauty, ductility, and indestructibility. But platinum, though perhaps inferior in few of these qualities, and certainly far superior in others, was unknown in Europe, as a distinct metal, before the year 1749.†

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* Hjelm, Crell's Annals, iii. 356, Eng. Trans.

† Father Cortinovis, indeed, has attempted to prove that this metal was the *electrum* of the ancients. See the Chemical Annals of Brugnatelli, 1790. That the *electrum* of the ancients was a metal, and a very valuable one, is evident from many of the ancient writers, particularly Homer. The following lines of Claudian are alone sufficient to prove it:

    " Atria cinxit ebur, trabibus solidatur ahenis

    " Culmen et in celsas surgunt *electra* columnas." L. I. v. 164.

Pliny gives us an account of it in his Natural History. He informs us that it was a composition of silver and gold; and that by candle-light it shone with more splendour than silver. The ancients made cups, statues, and columns of it. Now, had it been our platinum, is it not rather extraordinary that no traces of a metal, which must have been pretty abundant, should be perceptible in any part of the old continent?

As the passage of Pliny contains the fullest account of electrum to be found in any ancient author, I shall give it in his own words, that every one may have it in his power to judge whether or not the description will apply to the platinum of the moderns.

I. It has hitherto been found only in Choco in Peru, in the mine of Sánta Fe, near Carthagena; in Brazil, and in the valley of Jaky in St. Domingo. About the year 1820 it was discovered on the east side of the Oural mountains, between Nijné-Tajibskoi and Kutschtumskoi. In all of these situations it occurs in grains in alluvial soil, accompanied by fragments of greenstone and syenite. M. Boussingault has lately discovered it in situ in decomposed syenitic rocks at Santa Rosa, about 30 miles north-east from Medellin, in the province of Antioquia, in north latitude 6° 37′ 43″, situated 7462 feet above the level of the sea.* Even in the veins where the ore occurs it is in grains, which have the appearance of having been water-worn. Humboldt has expressed his opinion that this syenite, in which veins containing grains of gold and of platinum are situated, belongs to the same formation as the zircon syenite of Norway. The rock in which the platinum occurs in Brazil appears to be a chloritous quartz. The Oural locality seems to be a syenite.

It occurs in small plates, having the metallic lustre, and in which the platinum is alloyed with six or more other metals. In general these plates or scales are very small, though they now and then occur of a large size. In the year 1814, a negro slave found at Condoto in the province of Choco, a mass of platinum weighing one pound nine ounces and a drachm, which was deposited in the Royal Museum at Madrid.† The workmen of the American mines must no doubt have been early acquainted with it; and indeed some of its properties are obscurely mentioned by some of the writers of the 16th century. Mr. Charles Wood, assay-master in Jamaica, saw it in the West Indies about the year 1741. He gave some specimens of it to Dr. Brownrigg, who presented it to the

"Omni auro inest argentum vario pondere.—Ubicunque quinta argenti portio est, *electrum* vocatur. Scrobes eæ reperiuntur in Canaliensi. Fit et cura electrum argento addito. Quod si quintam portionem excessit incudibus non resistit. Et electro auctoritas, Homero teste, qui Menelai regiam auro, electro, argento, ebore fulgere tradit. Minervæ templum habet Lindos insulæ Rhodiorum in quo Helena sacravit calicem ex electro.—Electri natura est ad lucernarum lumina clarius argento splendere. Quod est nativum et venena deprehendit. Namque discurrunt in calicibus arcus cœlestibus similes cum igneo stridore, et gemina ratione prædicunt."—Lib. xxxiii. cap. iv.

* Ann. de Chim. et de Phys. xxxii. 204.

† Vauquelin discovered it in considerable quantity in the silver mines of Guadalcanal, in the province of Estremadura in Spain. But this analysis has never been confirmed by repetition. Ann. de Chim. lx. 317.

Royal Society in 1750. In 1748 it was noticed by Don Antonio de Ulloa, a Spanish mathematician, who, in 1735, had accompanied the French academicians to Peru in their voyage to measure a degree of the meridian. A paper on it was published by Mr. Wood in the 44th volume of the Philosophical Transactions for 1749 and 1750. Dr. Lewis began a set of experiments on it in 1749, the result of which was published in four papers in the Philosophical Transactions for 1754, and afterwards two other papers were added.* These experiments demonstrate its peculiar nature and its remarkable properties. In 1752, Scheffer of Sweden published a dissertation on this metal, remarkable for its precision, if we consider the small quantity of ore on which he had to work, which was not more than 40 grains. The experiments of Lewis were repeated, and many curious additions made to them by Margraff in 1757.† These dissertations having been translated into French, drew the attention of the chemists of that country, and induced Macquer and Baumé‡ to make a set of experiments on platinum, which were soon followed by the experiments of Buffon, Tillet, and Morveau;§ Sickengen,‖ Bergman,¶ Lavoisier,** and more lately Mussin Puschkin,†† and Morveau;‡‡ and several other chemists of eminence have added to our knowledge of this mineral. But the experiments of Berzelius§§ and Edmond Davy‖‖ have added most to our knowledge of its combinations.

How reduced.   The process for reducing crude platina to an ingot of pure malleable platinum, was brought to perfection by Dr. Wollaston, who had the merit of first supplying chemists with vessels of this metal, before which accurate experimenting was nearly impracticable. Dr. Wollaston's process is remarkable for its extreme simplicity. The grains of crude platina are put into a retort, with a sufficient quantity of dilute aqua regia. The muriatic acid used should be diluted with an equal measure of water, and the nitric acid should be what is called single aqua fortis. A quantity of muriatic acid equivalent to 150 marble, together with nitric acid equivalent to 40 marble, will take up

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* Phil. Trans. xlviii. 638, and l. 148. See also Phil. Com. p. 443, for a full detail of all the experiments on this metal made before 1763.

† Mem. Berlin, 1757, p. 31, and Margraff's Opusc. ii. 226.

‡ Mem. Par. 1758, p. 119.   § Jour. de Phys. iii. 234.

‖ Macquer's Dictionary.   ¶ Opusc. ii. 166.

** Ann. de Chim. v. 137.   †† Ann. de Chim. xxiv. 205.

‡‡ Ibid. xxv. 3.

§§ Ibid. lxxxiii. 167, and Kongl. Vet. Acad. Hand. 1828, p. 25.

‖‖ Phil. Mag. xl. 27, 209, 263, 350.

100 of crude platina. But at least 120 of the ore should be introduced instead of 100. The acids should be allowed to digest for three or four days with a heat which should be gradually raised. Being then poured off it should be allowed to stand till a fine powder of ore of iridium suspended in it has had time to subside. It should then be mixed with 41 parts of sal ammoniac previously dissolved in five times its weight of water.*

The yellow precipitate must be thoroughly washed, and ultimately pressed to remove the last remnant of the washings. It is next to be heated with extreme caution in a black lead pot, just sufficiently high to drive off the sal ammoniac, and to occasion the particles of platinum to adhere as little as possible; for upon this depends the success of the subsequent parts of the process. The gray product of platinum is now to be rubbed between the hands of the operator to reduce it to a powder fine enough to pass through a lawn sieve. The coarser parts are then to be ground in a wooden bowl with a wooden pestle, till the whole is reduced to powder. They must not be touched by any thing hard enough to burnish their surface, otherwise the process is spoiled. The powder is now to be put into a brass mould filled with water, taking care that no vacuities are left. The top of the powder is first covered with a circle of paper and then with one of cloth, and it is afterwards compressed with the force of the hand by a wooden plug. A circular plate of copper is next laid on the top. It is then exposed to a very violent pressure in a horizontal press.† It is now placed in a charcoal fire, and there heated to redness to drive off water, &c. and give it a firmer cohesion.

The next process is to place upon an earthen stand about 2½ inches above the grate of a wind furnace (the stand being strewed over with a layer of clean quartzose sand,) the ingot of platinum standing on its end, covered by a very refractory crucible not touching it, and to expose it for about 20 minutes to the highest temperature that can be raised in the furnace. It is now to be placed on an anvil and struck while hot on the top with a heavy hammer, so as at one heating effectually to close the metal. It must never be struck on the sides; which

* The mother liquor still retains about 11 parts of platinum, which should be precipitated by a bar of iron, and dissolved in a proportional quantity of aqua regia.

† The reader will find a description of this press in Phil. Trans. 1829, p. 4.

would cause it to crack.   By this hammering it is brought into the state of a perfect ingot fit for all purposes.[*]

I. Platinum, thus obtained, is of a white colour, like silver, but not so bright.[†]   It has no taste nor smell.   Its hardness is intermediate between that of copper and iron.   Its specific gravity when reduced from the ammonio-muriate by heat is 21·47.   By hammering it may be increased $\frac{1}{350}$th: so that its maximum specific gravity is 21·5313.[‡]   It is exceedingly ductile and malleable; it may be hammered out into very thin plates, and drawn into wires not exceeding $\frac{1}{1940}$ inch in diameter.   In these properties it is probably inferior to gold, but it seems to surpass all the other metals.   Its tenacity is such, that a wire of platinum 0·078 inch in diameter is capable of supporting a weight of 274·31 lbs. avoirdupois without breaking.[§] It is one of the most infusible of all metals, and cannot be melted in any quantity at least, by the strongest artificial heat which can be produced.   Macquer and Baumé melted small particles of it by means of a blow-pipe, and Lavoisier by exposing them on red-hot charcoal to a stream of oxygen gas.[||] It may be indeed melted without difficulty when combined or mixed with other bodies, but then it is not in a state of purity. Pieces of platinum, when heated to whiteness, may be welded together by hammering in the same manner as hot iron.   This metal is not in the smallest degree altered by the action of air or water.

Oxides.   II. It cannot be combined with oxygen and converted into an oxide by the strongest artificial heat of our furnaces.   Platinum, indeed, in the state in which it is brought from America, may be partially oxidized by exposure to a violent heat, as numerous experiments have proved; but in that state it is not pure, but combined with a quantity of iron.   It cannot be doubted, however, that if we could subject it to a sufficient heat, platinum would burn, and be oxidized like other metals; for when Van Marum exposed a wire of platinum to the action

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* Phil. Trans. 1829, p. 1.
† To this colour it owes its name.   *Plata*, in Spanish, is " silver;" and *platina*, " little silver," was the name first given to the metal.   Bergman changed that name into *platinum*, that the Latin names of all the metals might have the same termination and gender.   It had been, however, called *platinum* by Linnæus long before.
‡ Dr. Wollaston.   § Morveau, Ann. de Chim. xxv. 7.
|| Dr. Clarke, by means of his oxygen and hydrogen gas blow-pipe, melted pieces of platinum weighing 100 grains.

of his powerful electrical machine, it burnt with a faint white
flame, and was dissipated into a species of dust, which proved
to be the oxide of platinum. By putting a platinum wire into
the flame produced by the combustion of hydrogen gas mixed
with oxygen, I caused it to burn with all the brilliancy of iron
wire, and to emit sparks in abundance.

At present only two oxides of platinum are known; the *prot-oxide* has a *black* colour, but the *peroxide* is *dark brown*.

1. To obtain protoxide of platinum, we must dissolve the
metal in nitromuriatic acid, evaporate the solution to dryness,
and, after reducing the dry salt to powder expose it on a por-
celain cup to the temperature at which tin melts. Chlorine
gas is driven off, and a greenish gray powder remains, which
is insoluble in water, and seems to be a protochloride of plati-
num. If we digest this chloride in a caustic alkaline ley at a
gentle heat a portion is dissolved, but a black powder remains,
which, when well washed and dried, is protoxide of platinum.
This black powder is a hydrate : when heated in a retort it
gives out water and oxygen gas. When heated to redness
with combustible bodies it detonates feebly. When digested
in acids it is generally reduced partly to the metallic state and
partly to peroxide of platinum.

2. Mr. Cooper has given us another process for obtaining a black
oxide of platinum, namely, pouring a neutral solution of mercury
into a dilute solution of muriate of platinum in hot water. A
dense powder precipitates, varying in colour from deep brown to
yellow and sometimes olive green. It is a mixture of calomel and
protoxide of platinum. It must be carefully washed and dried,
and then exposed to a heat just sufficient to volatilize the calomel.
A deep black powder remains, which is the protoxide. One hun-
dred grains of it when heated to redness give off $12\frac{1}{2}$ cubic
inches of oxygen gas, and are reduced to the metallic state.
When heated with lamp black it gives out the same proportion
of carbonic acid, and is reduced to the metallic state. Mr.
Cooper, to whom we are indebted for the discovery of this
oxide, found that it might be heated strongly when mixed with
enamellers' flux without being reduced. On this account he
considers it as a valuable addition to the colours of enamellers.*

It is obvious that the black oxide of Mr. Cooper is not the
same with that from the protochloride. For Berzelius analyzed
this last, and found it a compound of 100 platinum and 8·225

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* Royal Institution Journal, iii. 119.

of oxygen; while Mr. Cooper's oxide is a compound of 100 platinum and 4·52 oxygen. I have shown, by experiments which I consider as conclusive, that the atomic weight of platinum is 12.* It is obvious that the black oxide from the protochloride is a compound of

1 atom platinum	. .	12
1 atom oxygen	. .	1
		—
		13

While Mr. Cooper's is a *suboxide* composed of

2 atoms platinum	. .	24
1 atom oxygen	. .	1
		—
		25

3. Peroxide. 3. It is rather difficult to procure the peroxide of platinum, and I am not sure that it ever has been examined in a state of complete purity. The process which yields it in the state of greatest purity is this: Through a neutral solution of platinum in aqua regia pass a current of sulphuretted hydrogen gas. A black precipitate falls, which is sulphuret of platinum. Wash it and dissolve it in nitric acid, evaporate the solution to dryness, and continue the heat till all the nitric acid is driven off. What remains is sulphate of platinum, which dissolves in water, forming a dark-brown solution. Drop a solution of nitrate of barytes into the solution till all sulphuric acid is thrown down, then filter and pour caustic potash or ammonia into the liquid. One half of the platinum falls down in the state of peroxide, the remaining half constituting a double salt remains in solution. The peroxide thus obtained is a yellowish-brown bulky powder, which becomes darker coloured when dried, and then has a great resemblance to the rust of iron. In this state it is a hydrated oxide. When heated it gives out water and becomes dark brown or almost black. If the heat be raised to incipient redness, oxygen gas is given out, and the platinum reduced to the metallic state. Its tendency to combine with acids is very small. It seems in reality to possess slightly acid qualities, and to have a tendency to unite with bases. It would appear from the experiments of Berzelius that this oxide contains just twice as much oxygen as the protoxide. It is therefore a compound of

* First Principles, i. 450.

1 atom platinum	.	.	12
2 atoms oxygen	.	.	2

$$\overline{14}$$

4. Mr. Edmond Davy discovered that if sulphate of platinum be precipitated by caustic ammonia, and the precipitate be boiled in a weak potash ley to extract all the sulphuric acid, we obtain a powder which has the property of fulminating when heated to about 417°. When this powder is treated with nitric acid, and cautiously heated a gray powder remains undissolved, which, according to the analysis of Mr. E. Davy, is composed of 100 platinum and 11·86 oxygen. This approaches to

1 atom platinum	.	.	12
1½ atom oxygen	.	.	1·5

$$\overline{13·5}$$

These experiments afford a presumption that the gray powder is a sesquioxide of platinum. Thus from the facts just related the presumption is that there exist four different oxides of platinum, the constituents of which may be thus represented:

	Platinum.	Oxygen.		Platinum.		Oxygen.
1. Suboxide	2 atoms	+ 1	atom or	24	+	1
2. Oxide	1	+ 1		12	+	1
3. Sesquioxide	1	+ 1·5		12	+	1·5
4. Peroxide	1	+ 2		12	+	2

But these oxides have not hitherto been examined with sufficient care to induce us to put much confidence in the statement just given. The only point which I consider as determined with certainty is that 12 denotes the atomic weight of platinum.

III. Platinum does not take fire when introduced into chlorine gas; but it slowly imbibes the gas, and is converted into a *chloride*. We are at present acquainted with only two compounds of chlorine and platinum.

1. To obtain the *protochloride* platinum is to be boiled in strong muriatic acid, adding occasionally a little nitric acid. The solution is to be evaporated to dryness, and then digested with a little muriatic acid, which is likewise to be driven off. The dry mass is to be cautiously heated nearly to redness and boiled with a considerable quantity of water. Being now dried it is pure chloride of platinum.

Its colour is dull olive-brown or green. It has rather a harsh feel; but is destitute of taste and smell. It is infusible. It does not appear to be altered by exposure to the atmosphere,

and it is insoluble in water, but dissolves in perchloride of platinum. When heated to redness the chlorine is driven off, and pure platinum remains. It is slightly soluble in boiling muriatic acid, but it is insoluble in nitric, sulphuric, phosphoric, and acetic acids. When boiled in potash ley a black powder is obtained, which yields both oxygen and chlorine by heat. When it is heated with sulphur or phosphorus, chlorides of sulphur and phosphorus are obtained, and phosphuret or sulphuret of platinum. According to the experiments of Mr. Edmond Davy, it is composed of 100 platinum, and 37·93 chlorine. This is obviously

1 atom platinum	.	.	12
1 atom chlorine	.	.	4·5
			16·5

2. The perchloride of platinum is obtained by dissolving platinum in nitromuriatic acid, and cautiously evaporating the solution to dryness to drive off all excess of acid. A reddish brown matter remains, which dissolves in water, forming a reddish yellow coloured solution, which is much employed by chemists in separating potash from soda; an important analytical process, for which chemistry is indebted to Dr. Wollaston. It would not be easy to analyze this chloride; but it enters into combination with the chlorides of potassium, sodium, and ammonium, forming double chlorides, which constitute regular salts. By the analysis of these chlorine salts it has been ascertained that the perchloride of platinum is a compound of

1 atom platinum	.	.	12
2 atoms chlorine	.	.	9
			21

Bromide.   IV. Platinum is not acted upon by bromine or its vapour at the ordinary temperature of the atmosphere; but it dissolves in bromonitric acid, and a yellow coloured bromide is formed, decomposable and capable like the perchloride of platinum of forming insoluble yellow precipitates in salts of potash and ammonia.*

Iodide.   V. Pleischl has observed that when iodic acid is dropt into a solution of bichloride of platinum a yellow precipitate falls, somewhat soluble in water.

' Balard; Ann. de Chim. et de Phys. xxxii. 862.

VI. No combination of platinum with hydrogen, azote, or carbon, is known.

VII. It was observed by Descotils and Chenevix* that when platinum surrounded with charcoal was strongly heated it fused, and they considered the button formed as a carburet of platinum. But the subject was reviewed by M. Boussingault, who found that the fused platinum had increased about half a per cent. in weight, that it had assumed a grayish colour, had become excessively hard, and was with difficulty acted on by the file. Its specific gravity was reduced to 20·5. It had lost much of its malleability, and soon breaks under the hammer. On dissolving it in aqua regia there remained one per cent. of silica. It appears from this that when platinum is heated along with charcoal powder, it unites with a portion of silicon, which doubtless existed in the charcoal powder. Accordingly when M. Boussingault made use of lamp-black instead of charcoal, the platinum did not fuse nor undergo any alteration.† This silicet of platinum appears to be composed of.

$33\frac{1}{3}$ atoms platinum
1 atom silicon.

VIII. Descotils heated a mixture of platinum, borax, and charcoal. The platinum melted into a hard, brittle, somewhat crystalline button, which, when dissolved in aqua regia, left a quantity of boracic acid behind. It would appear from this that a boret of platinum had been formed by him.

IX. The affinity which exists between platinum and phos- phorus is so considerable, that if we heat strongly a phosphate mixed with charcoal in a platinum crucible, we destroy the crucible by converting it into a phosphuret. Three different phosphurets have been described.

1. When platinum is heated with a mixture of phosphoric glass and charcoal powder, or when phosphorus is thrown upon red-hot platinum, a combination is formed. The phosphuret is silver white, hard, crystalline, and more fusible than silver. Pelletier in this way made a phosphuret composed of 100 platinum and 28 phosphorus. This approaches

2 atoms phosphorus	. .	4
1 atom platinum	. .	12
		16

though not very nearly.

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* Ann. de Chim. lxvii. 98.   † Ann. de Chim. et de Phys. xvi. 5.

2. Mr. Edmond Davy formed a phosphuret of platinum by heating phosphorus and platinum in an exhausted glass tube. At a temperature considerably below redness they combine with vivid ignition and flame. Thus phosphuret of platinum has a bluish-gray colour. When it has undergone fusion its lustre is little inferior to that of lead. It crystallizes in cubes. Its specific gravity while porous is 6. It is destitute of taste and smell. It is a nonconductor of electricity. When strongly heated on platinum it unites with the metal which it perforates with holes. According to the experiments of Mr. Edmond Davy, it is composed of 100 platinum and 21·21 of phosphorus. This is nearly equivalent to

$1\frac{1}{4}$ atoms phosphorus	. .	2·5
1 atom platinum	. .	12
		———
		14·5

3. Another phosphuret was formed by Mr. Davy by heating together *ammonio-chloride of platinum* with about two-thirds of its weight of phosphorus, in small bits, in a retort over mercury. Towards the end of the experiment the retort should be heated to a dull red, to expel every thing volatile. This perphosphuret of platinum has an iron-gray colour and a slight metallic lustre. It stains the fingers or paper, but the lustre is inferior to that communicated by persulphuret of platinum. Specific gravity 5·28. It is destitute of taste and smell, and is a nonconductor of electricity. When heated it becomes ignited and diminishes in bulk without changing its colour. According to the experiments of Mr. Edmond Davy, it is composed of 100 platinum, 42·85 phosphorus. This is nearly equivalent to

$2\frac{1}{2}$ atoms phosphorus	. .	5
1 atom platinum	. .	12
		—
		17

It is not unlikely that the true composition of these phosphurets may be

Phosphorus.		Platinum.
$2\frac{1}{2}$ atoms	+	1 atom
2	+	1
$1\frac{1}{2}$	+	1

But new experiments would be requisite to clear up the subject.

Sulphurets.   X. Platinum combines with three proportions of sulphur.

For the investigation of these compounds we are indebted to Mr. Edmond Davy.*

1. Protosulphuret of platinum was formed by mixing equal weights of sulphur and platinum in an exhausted glass tube and heating them together. Towards the end of the process the mass was heated nearly to redness to expel every thing volatile. Protosulphuret of platinum thus formed is of a dull bluish-gray colour. Its lustre is earthy; but when rubbed on paper it leaves a metallic stain. Its feel is rather harsh. It has no smell or taste. Its specific gravity is 6·2. It is a non-conductor of electricity. It is decomposed when heated with zinc filings. According to the analysis of Mr. Edmond Davy, its constituents are, 100 platinum and 19·04 sulphur: Had the sulphur united to 100 platinum, been only 16·66 instead of 19, the sulphuret would have been a compound of

1 atom sulphur	. .	2
1 atom platinum	. . .	12
		—
		14

Now this is the composition assigned by Berzelius, but probably only from theoretical views.

2. When platinum is precipitated from its solution in aqua regia by a current of sulphuretted hydrogen gas, a black sulphuret is obtained which must be dried in vacuo over sulphuric acid, otherwise it absorbs oxygen, and is converted into sulphate of platinum during the process of drying, as was first observed by Mr. Edmond Davy. We have two analyses of this sulphuret. According to Vauquelin, it is the same as the last sulphuret, while Mr. E. Davy makes it a compound of

1½ atom sulphur	.	3
1 atom platinum	.	12
		—
		15

The opinion of Vauquelin has been generally adopted. From theoretical considerations, we should be led to expect that it should contain 2 atoms of sulphur.

3. Persulphuret of platinum is obtained by heating a mixture of 3 parts of ammonio-muriate of platinum and 2 parts of sulphur in a glass retort over mercury. The mixture must be gradually heated to redness, and continued for some time in that heat till every thing volatile be expelled. It has a dark

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* Phil. Mag. xl. 27, 219.

iron-gray colour approaching to black.   When in lumps it has a slight metallic lustre.   It has a soft feel, and when rubbed on paper leaves a stain similar to that of black lead.   Its specific gravity is 3·5.   It is a nonconductor of electricity.   It does not melt though exposed to a very strong heat.   When heated with zinc filings combustion takes place and sulphuret of zinc is formed.   When heated to redness in the open air the sulphur is expelled and pure platinum remains.   According to the analysis of Mr. Edmond Davy, its constituents are, 100 platinum 38·8 sulphur.   'This is obviously

$$
\begin{array}{llll}
\text{2 atoms sulphur} & . & . & 4 \\
\text{1 atom platinum} & . & . & 12 \\
\hline
& & & 16
\end{array}
$$

Seleniet.   XI. Selenium combines readily with platinum in powder, with the evolution of a great deal of heat.   The seleniet is gray, and has not undergone fusion.   When heated the selenium combines with oxygen and flies off, leaving the platinum pure.   When seleniates are heated to redness in platinum crucibles, the vessels are attacked and acquire a brownish-gray colour.   But if heat be applied to the uncovered crucible the selenium flies off.[*]

Arseniet.   XII. The alloy of arsenic and platinum was first examined by Scheffer, and afterwards by Dr. Lewis.   The addition of white oxide of arsenic causes strongly heated platinum to melt; but the mixture does not flow thin, and cannot be poured out of the crucible.   The alloy is brittle and of a gray colour.   The arsenic is mostly expelled in a strong heat, leaving the platinum in the state of a spongy mass.[†]

When 100 platinum is heated with its own weight of arsenic the alloy weighs 173·5 parts.   This is nearly

$$
\begin{array}{llll}
\text{2 atoms arsenic} & . & . & 9·5 \\
\text{1 atom platinum} & . & . & 12 \\
\hline
& & & 21·5
\end{array}
$$

Antimoniet.   XIII. Platinum easily combines with antimony.   The alloy of equal parts is brittle, and of a much duller colour than antimony.   The antimony cannot afterwards be completely separated by heat.   When the antimony exceeds, the platinum is apt to subside in slow cooling.[‡]

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[*] Berzelius; Ann. de Chim. et de Phys. x. 249.
[†] Phil. Com. p. 515.   [‡] Lewis, Phil. Com. p. 521.

Mr. Fox has observed that antimony and platinum combine with great rapidity and with ignition. He is of opinion that platinum by alloying it with antimony, and then driving off the antimony by heat, may be rendered sufficiently pure for the purposes of manufacturers.*

XIV. Equal parts of platinum and molybdenum melted into a hard irregular brittle mass, of a close texture, a light gray colour, and a metallic lustre. Three parts of molybdenum, and one of platinum, did not melt completely. The same difficulty of fusion was experienced when the proportion of platinum was augmented. The specific gravity of this alloy was found by Hjelm to be 20.†

XV. Platinum unites with potassium and sodium with ignition, as Sir H. Davy first ascertained. The alloy is decomposed by the action of air or water.

XVI. We are ignorant of the alloys which platinum is capable of forming with the metallic bases of the alkaline earths and earths proper.

XVII. Platinum is usually found alloyed with iron. Dr. Lewis did not succeed in his attempts to unite these metals by fusion, but he melted together cast iron and crude platina, and likewise steel and crude platina. The alloy was excessively hard, very tough, and possessed some ductility when the iron was about $\frac{3}{4}$ths of the alloy. The specific gravity greatly exceeded the mean; the platina having destroyed the property which cast-iron has of expanding when it becomes solid. This alloy, after being kept ten years, was very little tarnished. At a red heat it was brittle, and appeared, when broken, to be composed of black grains, without any metallic lustre.‡ Mr. Stodart and Mr. Faraday found that the toughness and smoothness of steel were very much improved by alloying it with $\frac{1}{100}$th of its weight of platinum. They recommend this alloy as particularly valuable for articles of cutlery.§

XVIII. We are unacquainted with the alloys which platinum forms with nickel, cobalt, manganese, uranium, and cerium.

XIX. Dr. Lewis found that platinum unites with the fumes of zinc reduced from its ore, and acquires about $\frac{1}{3}$d of additional weight. The two metals very readily melt, even when

* Annals of Philosophy, xiii. 467.
† Hjelm, Crell's Annals, iii. p. 52, Eng. Trans. and Ann. de Chim. iv. 17.
‡ Phil. Com. pp. 534 and 551.   § Phil. Trans., 1822, p. 257.

the zinc does not exceed $\frac{1}{4}$th of the platinum. The alloy is very brittle, of a bluish white colour, and much harder than zinc. One twentieth of platinum destroys the malleability of zinc, and $\frac{1}{4}$th of zinc renders platinum brittle.*

Cadmium,   XX. The alloy of platinum and cadmium has a light silver white colour. It is granular, and has a conchoidal fracture. It is very brittle and very fusible. When heated till the excess of cadmium is driven off, it is composed of 100 platinum and 117·3 cadmium. This is equivalent to

<div style="text-align:center">

2 atoms cadmium   .   .   14

1 atom platinum   .   .   12

—

26

</div>

Bismuth,   XXI. Bismuth and platinum readily melt and combine when exposed rapidly to a strong heat. Dr. Lewis fused the metals in various proportions, from 1 of bismuth to 24 with 1 of platinum. The alloys were all as brittle, and nearly as soft, as bismuth; and when broken, the fracture had a foliated appearance. When this alloy is exposed to the air, it assumes a purple, violet, or blue colour. The bismuth can scarcely be separated by heat.†

Lead,   XXII. Dr. Lewis fused crude platina and lead together in various proportions; a violent heat was necessary to enable the lead to take up the platinum. Hence a portion of the lead was dissipated. The alloys had a fibrous or leafy texture, and soon acquired a purple colour when exposed to the air. When equal parts of the metals were used, the alloy was very hard and brittle; and these qualities diminished with the proportion of platinum. When the alloys were melted again, a portion of the platinum subsided.‡ Many experiments have been made with this alloy, in order, if possible, to purify platinum from other metals by cupellation, as is done successfully with silver and gold. But scarcely any of the experiments have succeeded: because platinum requires a much more violent heat to keep it in fusion than can be easily given.§

Tin,   XXIII. From the experiments of Dr. Lewis we learn, that tin and platinum readily melt, and form an alloy which is brittle and dark coloured when the proportions of the two metals are equal, and continues so till the platinum amounts only to $\frac{1}{9}$th of the alloy; after this the ductility and white

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* Phil. Com. p. 520.   † Ibid. pp. 509, 573.

‡ Ibid. p. 512.   § Ibid. p. 561.

colour increase as the proportion of platinum diminishes.
When this alloy is kept, its surface gradually tarnishes and
becomes yellow, but not so readily if it has been polished.*

When tinfoil and platinum foil are wrapt up together and
exposed to the action of the blow-pipe, or simply to the flame
of a candle, they combine instantaneously with the evolution
of a great deal of light and heat which continues for some
time. This curious experiment was first made by Mr. Robert
Fox of Falmouth;† and has been since very often repeated,
especially by Dr. Clarke.‡

XXIV. Platinum may be alloyed with copper by fusion,
but a strong heat is necessary. The alloy is ductile, hard,
takes a fine polish, and is not liable to tarnish. This alloy has
been employed with advantage for composing the mirrors of
reflecting telescopes. The platinum dilutes the colour of the
copper very much, and even destroys it, unless it be used spar-
ingly. For the experiments made upon it we are indebted to
Dr. Lewis.§ Strauss has lately proposed a method of coat-
ing copper vessels with platinum instead of tin; it consists in
rubbing an amalgam of platinum over the copper, and then
exposing it to the proper heat.‖

XXV. Mr. Cooper has formed an alloy of 7 parts platinum,
16 copper, and 1 zinc, that has much the appearance of pure
gold. The copper and platinum are first fused, with the usual
precautions of covering the metals with charcoal and adding
a flux of borax. When it is in perfect fusion it is removed
from the fire, the zinc is added, and the mixture stirred. This
alloy is very ductile, is not oxidized by exposure to the air,
and is not dissolved by nitric acid except at a boiling heat.¶

XXVI. Dr. Lewis attempted to form an amalgam of plati-
num, but succeeded only imperfectly, as was the case also with
Scheffer.** Guyton Morveau succeeded by means of heat.
He fixed a small cylinder of platinum at the bottom of a tall
glass vessel, and covered it with mercury. The vessel was
then placed in a sand-bath, and the mercury kept constantly
boiling. The mercury gradually combined with the platinum;
the weight of the cylinder was doubled, and it became brittle.
When heated strongly, the mercury evaporated, and left the

* Philos. Commerce, p. 510.   † Annals of Philosophy, xiii. 467.
‡ Ibid. xiv. 229, 470.   § Philos. Commerce, p. 529.
‖ Nicholson's Journal, ix. 303.
¶ Journal of the Royal Institution, iii. 119.
** Lewis, Phil. Com. p. 508.

Chap. III.   platinum partly oxidated.   It is remarkable that the platinum, notwithstanding its superior specific gravity, always swam upon the surface of the mercury, so that Morveau was under the necessity of fixing it down.*

The simplest and easiest way of combining platinum and mercury was pointed out by Muschin Pushkin. It consists in triturating with mercury the fine powder obtained by precipitating platinum from nitro-muriatic acid by sal ammoniac, and exposing the precipitate to a graduated heat. Some trituration is necessary to produce the commencement of combination; but when once it begins it goes on rapidly. Small quantities of the platinum and mercury are to be added alternately till the proper portion of amalgam is procured. The excess of mercury is then separated by squeezing it through leather. The amalgam obtained is of a fine silvery whiteness, and does not tarnish by keeping. At first it is soft, but gradually acquires hardness. It adheres readily to the surface of glass, and converts it into a smooth mirror.

Silver,   XXVII. When silver and platinum are fused together (for which a very strong heat is necessary), they form a mixture, not so ductile as silver, but harder and less white. The two metals are separated by keeping them for some time in the state of fusion; the platinum sinking to the bottom from its weight. This circumstance would induce one to suppose that there is very little affinity between them. Indeed Dr. Lewis found, that when the two metals were melted together, they sputtered up as if there were a kind of repugnance between them. The difficulty of uniting them was noticed also by Scheffer.†

And Gold.   XXVIII. Dr. Lewis found that gold united with platinum when they were melted together in a strong heat. He employed only crude platina; but Vauquelin, Hatchett, and Klaproth, have since examined the properties of the alloy of pure platinum

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* Ann. de Chim. xxv. 12.—This was doubtless owing to the strong cohesion which exists between the particles of mercury. If you lay a large mass of platinum upon the surface of mercury, it sinks directly on account of its weight; but a small slip (a platinum wire, for instance,) swims, being unable to overcome the cohesion of the mercury. However, if you plunge it to the bottom, it remains there in consequence of its superior weight. If heat be now applied to the bottom of the vessel, the wire comes again to the surface, being buoyed up by the hot mercury, to which it has begun to adhere. These facts explain the seeming anomaly observed by Morveau.

† Lewis's Philosoph. Commerce, p. 522.

and gold.* To form the alloy, it is necessary to fuse the
metals with a strong heat, otherwise the platinum is only dis-
persed through the gold. When gold is alloyed with this
metal, its colour is remarkably injured; the alloy having the
appearance of bell-metal, or rather of tarnished silver. Dr.
Lewis found, that when the platinum amounted only to $\frac{1}{6}$th,
the alloy had nothing of the colour of gold; even $\frac{1}{22}$ part of
platinum greatly injured the colour of the gold. The alloy
formed by Mr. Hatchett of nearly 11 parts of gold to 1 of pla-
tinum, had the colour of tarnished silver. It was very ductile
and elastic. From Klaproth we learn, that if the platinum
exceed $\frac{1}{17}$th of the gold, the colour of the alloy is much paler
than gold; but if it be under $\frac{1}{17}$th, the colour of the gold is not
sensibly altered. Neither is there any alteration in the duc-
tility of the gold. Platinum may be alloyed with a consider-
able proportion of gold without sensibly altering its colour.
Thus an alloy of 1 part of platinum with 4 parts of gold can
scarcely be distinguished in appearance from pure platinum.
The colour of gold does not become predominant till it con-
stitutes eight-ninths of the alloy.†

From these facts it follows, that gold cannot be alloyed
with $\frac{1}{10}$th of its weight of platinum, without easily detecting
the fraud by the debasement of the colour; and Vauquelin has
shown, that when the platinum does not exceed $\frac{1}{10}$th, it may
be completely separated from gold by rolling out the alloy into
thin plates, and digesting it in nitric acid. The platinum is
taken up by the acid while the gold remains. But if the quan-
tity of platinum exceeds $\frac{1}{10}$th, it cannot be separated com-
pletely by that method.‡

SECTION III.—OF PALLADIUM.

This metal was discovered by Dr. Wollaston in 1803, and
the first account of its properties circulated without any inti-
mation of the discoverer, or the source whence the metal was
obtained. It was examined by Mr. Chenevix, who endea-
voured to show that it was a compound of platinum and mer-
cury. But his attempt was unsuccessful. Soon after Dr.
Wollaston announced that he was the discoverer of palladium,
and that he had obtained it from crude platina. It has been

* Vauquelin, Manuel de l'Essayeur, p. 44.—Hatchett, on the Alloys of
Gold, &c. Phil. Trans. 1803.—Klaproth, Journal de Chimie, iv. 29.
† Klaproth, Journal de Chimie, iv. 29.
‡ Manuel de l'Essayeur, p. 48.

since examined by M. Vauquelin,* and two sets of experiments on it have been published by Berzelius.†

Dr. Wollaston separated palladium from crude platina by the following process :

Dissolve crude platina in nitro-muriatic acid, and into the solution, previously freed from any excess of acid, drop a quantity of *prussiate of mercury*.‡ In a short time the liquid becomes muddy, and a pale yellowish white matter falls down. This precipitate, washed, dried, and exposed to a strong heat, leaves a white matter, which is palladium.§ The powder of palladium thus obtained is to be combined with sulphur, and each cake of the sulphuret, after being fused, is to be finally purified by cupellation in an open crucible with borax and a little nitre. The sulphuret is then to be roasted in a low red heat, on a flat brick, and pressed when reduced to a pasty consistence into a square, or oblong, and perfectly flat cake. It is again to be roasted very patiently, at a low red heat, till it becomes spongy on the surface. During this process sulphur flies off in the state of sulphurous acid, especially when the heat is allowed to subside. The ingot is then to be cooled, and when cold is to be tapped with a light hammer, to beat down the spongy excrescences on the surface. The alternate roastings and tappings require the utmost patience and perseverance before the cake can be made to bear hard blows. But it may be made so flat, and so square, as to bear being passed through a flatting mill, and so laminated to any degree of thinness.‖

Properties. I. Palladium thus obtained is a white metal, which, when polished, bears a very close resemblance to platinum.

It is rather harder than wrought iron. Its specific gravity varies according to the state in which it is exhibited. When completely fused, Mr. Chenevix found it 11·871; but some of the pieces exposed to sale were as low as 10·972. I found the specific gravity of a piece of rolled palladium, which had been heated to redness and allowed to cool, 11·718. Vauquelin obtained it when rolled, as high as 12 and a small fraction.

* Ann. de Chim. lxxxviii. 167.
† Annals of Philosophy, iii. 354, and Kong. Vetens. Acad. Handl. 1828, p. 44.
‡ A salt to be described in a subsequent part of this Work.
§ Wollaston on the Discovery of Palladium, Philosophical Transactions, 1805.
‖ Phil. Trans. 1829, p. 7.

The specific gravity, as stated by M. Breant, is 12.*   This
nearly agrees with an experiment of Mr. Lowry, who found _____
it 12·148.

It seems to be as malleable as platinum itself.   It possesses
but little elasticity, breaks with a fibrous fracture, and appears
of a crystallized texture.

It is not altered by exposure to the air.   It requires a very
violent heat to fuse it. • Mr. Chenevix succeeded in melting
it, but was not in possession of the means of estimating the
temperature.

Vauquelin fused it on charcoal by a jet of oxygen gas.
When the heat was continued the metal boiled and burnt,
throwing out brilliant sparks.   A portion of the metal which
escaped the combustion was dissipated and condensed on the
surface of the charcoal in very small grains.   Platinum melted
in the same way does not burn like palladium, which shows
that this last metal is more volatile and more combustible.

II. When strongly heated its surface assumes a blue colour ; Oxides.
but by increasing the temperature the original lustre is again
restored.   This blue colour is doubtless a commencement of
oxidizement.   But it is entirely superficial, and does not occa-
sion any sensible increase in the weight of the metal.   It is
removed by passing a current of hydrogen gas over the hot
metal.   From the recent experiments of Berzelius, it appears
that palladium combines with two proportions of oxygen, and
forms two oxides, which have been hitherto very imperfectly
examined.

The protoxide may be obtained by fusing palladium in
powder with potash and a little nitre.   But this process is not
a good one.   We may obtain it also by dissolving palladium
in fuming nitric acid, evaporating the solution to dryness, and
exposing it to a heat approaching ignition till the nitric acid is
perfectly dissipated.   The protoxide of palladium is a black
powder, tasteless and insoluble in water. · It does not readily
dissolve in acids, and requires boiling before we can obtain a
complete solution of it in muriatic acid.   When precipitated
from nitric acid by an alkali, we obtain it in the state of brown-
ish yellow hydrate.   There is reason to suspect that it is solu-
ble in alkaline leys. • From the analysis of the chloride of pal-
ladium by Berzelius, which will be stated below, there is reason
to believe that the atomic weight of this metal is 6·75.   If this

* Schweigger's Jahrbuch, ix. 357.

number be a near approximation to the truth, the protoxide will be a compound of

* 1 atom palladium	.	.	6·75
1 atom oxygen	.	.	1
			7·75

and its atomic weight will be 7·75.

III. From the late researches of Berzelius, we learn that the chlorides of palladium, like the oxides, are two.

1. Protochloride may be formed by dissolving the protoxide in muriatic acid, and evaporating to dryness. But in this state it has not hitherto been examined. It possesses the property, like the chloride of gold and platinum, of combining with the chlorides of potassium, sodium, and ammonium, and of forming with them crystallizable salts: showing that it possesses acid properties. Berzelius analyzed the potassium-chloride of palladium. In one experiment he found it a compound of

Chlorine	. .	.	4·5
Palladium	. .	.	6·93
Chloride of potassium	.	.	9·75
			21·18

and in another of

Chlorine	. .	.	4·5
Palladium	. .	.	6·801
Chloride of potassium	.	.	9·527
			20·828

The first of the chlorides had been fused. We see from the weight of chloride of potassium, that a little of the chlorine had been driven off. This makes the weight of palladium in the first analysis a little too high. In the second analysis the chloride had been strongly dried in a current of dry air. In it the weight of chloride of potassium approaches much nearer to 9·5, the true number; but it exceeds it a little. Hence I consider the weight of palladium 6·801, a little above the true ratio; because a little of the chlorine had even in this case been driven off. But these two analyses, compared with each other, leave little doubt that the true constitution of this chloride is

1 atom chlorine	.	.	.	4·5
1 atom palladium		.	.	6·75
1 atom chloride of potassium			.	9·5

20·75

This is my reason for pitching upon 6·75 as the atomic weight of palladium.

2. The perchloride of palladium has not hitherto been examined in a separate state. It has only been obtained combined with chloride of potassium. Berzelius obtained it by dissolving the preceding double chloride in aqua regia, and evaporating to dryness. Towards the end of the process deutoxide of azote is disengaged, and a red salt is deposited in microscopic crystals. These crystals consist of a combination of perchloride of palladium with chloride of potassium. Berzelius subjected them to analysis, and showed that they consist of

2 atoms chlorine	.	.	.	9
1 atom palladium	.	.	.	6·75
1 atom chloride of potassium		.	.	9·5

25·25

When these crystals are very small their colour is cinnabar red, but when large they are reddish brown. When heated chlorine is disengaged, and the protochloride fuses. Water decomposes this salt, chlorine being dissolved, and protochloride remaining undissolved. When boiled in water a great deal of chlorine is disengaged, muriatic acid remains in the liquid, and an oxide of the colour of amber precipitates.

The nature and properties of these double chlorides will come under our review in a subsequent part of this work.

IV. The bromides and iodides of palladium are still unexamined. Nor is any thing known respecting the compounds which this metal may be capable of forming with hydrogen, azote, boron, silicon, or phosphorus.

V. When a plate of palladium is put into the flame of a Carburet. spirit lamp near the wick, it becomes covered with a coating of soot which augments continually. If we burn this soot it leaves a metallic residue. A thin plate of palladium heated in this way becomes quite brittle. We see from this that palladium has an affinity for carbon.* There is reason to believe that platinum agrees with palladium in this property.

* Wöhler, Ann. des Mines, xii. 223.

VI. Palladium unites very readily to sulphur. When it is strongly heated, the addition of a little sulphur causes it to run into fusion immediately, and the sulphuret continues in a liquid state till it be only obscurely red-hot. Sulphuret of palladium is rather paler than the pure metal, and is extremely brittle. By means of heat and air, the sulphur may be gradually dissipated, and the metal obtained in a state of purity. According to the experiments of Vauquelin, the sulphuret of palladium is a compound of 100 palladium and 24 sulphur. This approaches

$$
\begin{array}{llr}
\text{1 atom palladium} & . & 6\cdot75 \\
\text{1 atom sulphur} & . & 2 \\
\hline
& & 8\cdot75
\end{array}
$$

But there is a slight excess of palladium. The reason of this may be that the metal retains a small portion of the sulphur obstinately.

VII. Palladium and selenium unite with facility, and heat is disengaged during the combination. The compound is gray and coherent, but has not undergone fusion. When it is exposed to the action of the blow-pipe, selenium is disengaged, and the alloy fuses into a grayish white metallic button, which is brittle, and has a crystalline fracture. Hence it still contains selenium.*

VIII. Mr. Chenevix alloyed palladium with various metals. The following are the results which he obtained:

1. " Equal parts of palladium and gold were melted together in a crucible. The colour of the alloy obtained was gray; its hardness about equal to that of wrought iron. It yielded to the hammer; but was less ductile than each metal separate, and broke by repeated percussions. Its fracture was coarse-grained, and bore marks of crystallization. Its specific gravity was 11·079.

2. " Equal parts of platinum and palladium entered into fusion at a heat not much superior to that which was capable of fusing palladium alone. In colour and hardness this alloy resembled the former; but it was rather less malleable. Its specific gravity I found to be 15·141.

3. " Palladium alloyed with an equal weight of silver, gave a button of the same colour as the preceding alloys. This was harder than silver, but not so hard as wrought iron; and its

* Berzelius, Ann. de Chim. et de Phys x. 248.

polished surface was somewhat like platina, but whiter. Its specific gravity was 11·290.

4. " The alloy of equal parts of palladium and copper was a little more yellow than any of the preceding alloys; and broke more easily. It was harder than wrought iron; and by the file, assumed rather a leaden colour. Specific gravity 10·392.

5. " Lead increases the fusibility of palladium. An alloy of these metals, but in unknown proportions, was of a gray colour, and its fracture was fine-grained. It was superior to all the former in hardness, but was extremely brittle. I found its specific gravity to be 12·000.

6. " Equal parts of palladium and tin gave a grayish button, inferior in hardness to wrought iron, and extremely brittle. Its fracture was compact and fine-grained. Specific gravity 8·175. •

7. " With an equal weight of bismuth, palladium gave a button still more brittle, and nearly as hard as steel. Its colour was gray; but when reduced to powder it was much darker. Its specific gravity I found to be 12·587.

8. " Iron, when alloyed with palladium, tends much to diminish its specific gravity, and renders it brittle. Arsenic increases the fusibility of palladium, and renders it extremely brittle."*

SECTION IV.—OF RHODIUM.

Rhodium was discovered by Dr. Wollaston in 1804. While Mr. Smithson Tennant was engaged in the examination of the black powder that remains undissolved when crude platina is treated with nitro-muriatic acid, Dr. Wollaston produced soda-muriate of rhodium, and presented it to Mr. Tennant as containing one of the new substances of which he was in quest. Mr. Tennant soon satisfied himself that it was quite different from his new metals. Upon this, Dr. Wollaston investigated its properties, and gave it the name of *rhodium*. It has been lately examined by Berzelius.†

It may be procured from crude platina by the following method of Wollaston:

The platina was freed from mercury by exposure to a red

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* See Chenevix's Inquiries concerning the Nature of a Metallic Substance called Palladium, Phil. Trans. 1803; and Wollaston's Paper on a New Metal found in Crude Platina, Ibid. 1804; and on the Discovery of Palladium, Ibid. 1805.

† Kong. Vet. Acad. Hand. 1828, p. 27.

heat, and from gold and other impurities by digestion in a small quantity of dilute nitro-muriatic acid in a moderate sand heat, till the acid was saturated, and the whole was dissolved, except a shining-black powder, from which the solution was separated. A solution of sal ammoniac in hot water was poured into this solution, in order to separate the platinum; the greatest part of which was precipitated in the form of a yellow powder. Into the solution thus freed from its platinum, a piece of clean zinc was immersed, and allowed to remain till it ceased to produce any farther effect. By the zinc a black powder was thrown down, which was washed and treated with very dilute nitric acid in a gentle heat, in order to dissolve some copper and lead with which it was contaminated. It was then washed and digested in dilute nitro-muriatic acid till the greater part was dissolved. To this solution some common salt was added. The whole was then gently evaporated to dryness, and the residuum washed repeatedly with small quantities of alcohol till it came off nearly colourless. By this means two metallic oxides are washed off in combination with common salt, namely, the oxides of platinum and palladium. There remained behind a deep red-coloured substance, consisting of the oxide of rhodium united to common salt. By solution in water and gradual evaporation, it forms rhomboidal crystals of a deep-red colour, whose acute angles are about 75°. When these crystals are dissolved in water, and a plate of zinc immersed in the solution, a black powder precipitates; which being strongly heated with borax becomes white, and assumes a metallic lustre. In this state it is rhodium. From Wollaston's analysis it follows, that crude platina contains about 1 part in 250 of rhodium.

Properties.　　I. Rhodium, thus obtained, is of a white colour, not much differing from that of platinum. Its specific gravity, according to Mr. Lowry, is 10·649. It is brittle, and requires a much higher temperature to fuse it than any other metal, unless iridium be an exception. Vauquelin was unable to fuse it on charcoal, though the combustion was increased by a jet of oxygen gas. Dr. Wollaston has never been able to fuse it so completely as to obtain it in a solid mass free from cavities. Its fracture is granular, and in hardness it appears fully equal to iron. Indeed, when Dr. Wollaston gave it to the London lapidaries to cut, they informed him that it was more injurious to their tools than the diamond itself.

It has the remarkable property of being insoluble in all acids.

Oxides.　　II. From the late researches of Berzelius, there is reason to

believe that rhodium combines with two proportions of oxygen,
and forms two *oxides.*

1. The peroxide may be procured by precipitating sodium-
chloride of rhodium with caustic potash, taking care not to add
the alkali in too great quantity, which would redissolve the pre-
cipitate. Yellow flocks fall, which constitute the peroxide.
When dried it assumes a brown colour, and it cannot be freed
from the precipitating alkali. When the heat is somewhat
strong it becomes *black.* Whether in this state it constitute
the protoxide is doubtful.* From the analysis of the perchlo-
ride of rhodium by Berzelius, which will be given below, there
is reason to believe that the atomic weight of this metal is 6·75,
and that the chlorine in the two chlorides are to each other as
1 to 1½. The oxides must be analogous, and of course the per-
oxide will be a compound of

1	atom rhodium	. .	6·75
1½	atom oxygen	. .	1·5
			8·25

so that its atomic weight will be 8·25.

2. When sulphurous acid was added to the potassium-chlo-
ride of rhodium, a pale yellow powder gradually fell, and the
red colour of the liquid diminished. When this precipitate was
dried it became almost white, and when heated gave out sul-
phurous acid and oxygen, and there remained bisulphate of
potash and oxide of rhodium. This salt seems to be a com-
pound of

1 atom sulphate of potash,
1 atom sesquisulphate of rhodium.

When carbonate of soda is mixed with a solution of this salt,
a gelatinous oxide precipitates of a deep greenish yellow colour.
This Berzelius considers as the protoxide of rhodium. But it
has not been examined nor obtained in a state of purity. The
protoxide is obviously a compound of

1	atom rhodium	. . .	6·75
1	atom oxygen	. .	1
			7·75

and its atomic weight is 7·75.

III. There are two chlorides of rhodium; which, however,

---

* I made no experiments on the *black oxide,* not being in possession of
enough of the oxide for any trials.

have not yet been obtained in an isolated state, but only in combination with chloride of potassium or sodium, with which they unite, in the manner of acids. The first of these is the sodium-chloride of rhodium, first obtained by Dr. Wollaston, and described in the beginning of this section. I analyzed this salt a good many years ago, and have stated the result in my " First Principles of Chemistry." I found the constituents

Rhodium	. .	5·5
Chlorine	. . .	4·5
Common salt	. .	7·5
Water	. . . .	11·25
		28·75*

Berzelius made two analyses of this salt, previously dried as much as possible. By the first he found the salt composed of

Rhodium	. .	4·461
Chlorine	. . . .	4·5
Common salt	. .	7·58
		16·541

By the second analysis he obtained

Rhodium	. . .	4·4605
Chlorine .	. .	4·5
Common salt	. .	7·421

He analyzed also the potassium-chloride of rhodium, which he found a compound of

Rhodium	. . .	4·412 or 6·618
Chlorine	. . . . .	4·5 or 6·75
Chloride of potassium	. .	6·309 or 9·464

This is evidently $1\frac{1}{2}$ atom of chloride of rhodium united to one atom of chloride of potassium. 'These analyses agree so nearly with each other that they are certainly very near the truth. As there is another chloride of rhodium, in which the chlorine is to the quantity united to the rhodium in the preceding analyses as two to three, there is every reason to consider these as compounds of 1 atom rhodium and $1\frac{1}{2}$ atom chlorine. If this be the case the atomic weight of rhodium will be by

* See " First Principles," p. 462.

1st analysis	6·69
2d	6·69
3d	6·618

3)19·998

Mean   6·666

But as the common salt in the second analysis, and the chloride of potassium in the third, are less than the atomic quantities, there is reason for suspecting a slight excess of chlorine in these salts, which would tend to sink the atom of rhodium a little below the truth. This is the reason why I have pitched upon 6·75 as a number that must be very near the truth.

2. When the peroxide of rhodium is digested in muriatic acid without the application of any artificial heat, a red solution is obtained, and there remains a grayish-red powder, which when dried, coheres together, and bears a moderate heat without decomposition. Berzelius has shown it to be a compound of 4·5 chlorine and 6·75 rhodium. We see, therefore, that it is protochloride. This analysis corroborates the propriety of assuming 6·75 for the atomic weight of rhodium.

IV. The other compounds of rhodium with simple bodies still remain unknown.

Though rhodium be insoluble in acids, and though its oxide obtained by heat is also nearly insoluble, Berzelius has shown that it may be dissolved by ignition in a covered platinum crucible along with bisulphate of potash. By this means it may be separated from platinum and iridium. Palladium is soluble likewise in bisulphate of potash. But if the two metals be reduced to the metallic state by a current of hydrogen gas, aqua regia will dissolve the palladium and leave the rhodium.

V. Rhodium unites readily with sulphur, and, like palladium, is rendered fusible by it; so also is it with arsenic. The arsenic or sulphur may be expelled by means of heat; but the metallic button obtained does not become malleable.

VI. The following are the result of the experiments made by Dr. Wollaston to alloy rhodium with other metals. Alloys.

" It unites readily with all metals that have been tried, excepting mercury; and with gold or silver it forms very malleable alloys, that are not oxidized by a high degree of heat, but become incrusted with a black oxide when very slowly cooled.

" When 4 parts of gold are united with 1 of rhodium, although the alloy may assume a rounded form under the blowpipe, yet

it seems to be more in the state of an amalgam than in complete fusion.

" When six parts of gold are alloyed with one of rhodium, the compound may be perfectly fused, but requires far more heat than fine gold. There is no circumstance in which rhodium differs more from platina than in the colour of this alloy, which might be taken for fine gold by any one who is not very much accustomed to discriminate the different qualities of gold. On the contrary, the colour of an alloy containing the same proportion of platina differs but little from that of platina. This was originally observed by Dr. Lewis. ' The colour was still so dull and pale, that the compound (5 to 1) could scarcely be judged by the eye to contain any gold.'*

" I find that palladium resembles platina in this property of destroying the colour of a large quantity of gold. When 1 part of palladium is united to 6 of gold, the alloy is nearly white.

" When I endeavoured to dissolve an alloy of silver or of gold with rhodium, the rhodium remained untouched by either nitric or nitro-muriatic acids; and when rhodium had been fused with arsenic or with sulphur, or when merely heated by itself, it was reduced to the same state of insolubility. But when 1 part of rhodium had been fused with 3 parts of bismuth, of copper, or of lead, each of these alloys could be dissolved completely in a mixture of 2 parts, by measure, of muriatic acid with 1 of nitric. With the two former metals, the proportion of the acids to each other seemed not to be of so much consequence as with lead; but the lead appeared on another account preferable, as it was most easily separated when reduced to an insoluble muriate by evaporation. The muriate of rhodium had then the same colour and properties as when formed from the yellow oxide precipitated from the original salt."†

Mr. Stodart and Mr. Faraday found that rhodium and steel could be melted together in any proportion. Equal parts of these two metals gave a button, which, when polished, exhibited a surface of the most exquisite beauty. It was the finest imaginable for a metallic mirror, did not tarnish by long exposure, and had a specific gravity of 9·176.‡ This was an alloy composed nearly of

2 atoms steel	. .	7
1 atom rhodium	. .	6·75

* Lewis's Phil. Com. p. 526.
† See Dr. Wollaston's paper, Phil. Trans. 1804.
‡ Phil. Trans. 1822, p. 256.

D₁, Wollaston made silver pens tipped with rhodium, which, from the great hardness of that metal, were not liable to be injured by use.

SECTION V.—OF IRIDIUM.

This metal was discovered by Mr. Smithson Tennant in 1803; but before he communicated the result of his experiments, a dissertation was published on it by Descotils in the Annales de Chimie, who had made the same discovery; and the subject was afterwards prosecuted more in detail by Vauquelin and Fourcroy.

When crude platina is dissolved in nitro-muriatic acid, especially if the acid be dilute, and only a moderate heat applied, there remains behind a quantity of black shining powder in small scales, which preceding chemists had mistaken for black lead. Mr. Tennant examined these scales, found their specific gravity to be 10·7, and that they consisted of two unknown metals united together. The first of these metals he called *iridium*, from the variety of colours which its solutions exhibit; to the second he gave the name of *osmium*, from the peculiar smell by which its oxides are distinguished.

Dr. Wollaston discovered, that in crude platina there exists another substance very similar to the grains of platina in appearance, but differing altogether in its properties. It consists of flat white grains, often distinctly foliated. They are not soluble in any acid, and their specific gravity is no less than 19·25, which is higher than that of any other mineral; the grains of platina by the trials of this accurate chemist not exceeding 17·5. These metallic grains are separated when the platina is dissolved in nitro-muriatic acid. Dr. Wollaston has ascertained them to be a compound of iridium and osmium. They are, therefore, of the same nature with the black powder examined by Mr. Tennant.

To separate the two metals from each other, the black powder is to be heated to redness in a silver crucible with its own weight of potash, and kept in that state for some time. The potash is then to be dissolved off by water. A solution is obtained of deep orange-colour. The portion of powder that remains undissolved is to be digested in muriatic acid. The acid becomes first blue, then olive-green, and lastly deep-red. The residual powder, which has resisted the action of these agents, is to be treated alternately with potash and muriatic acid, till the whole of it is dissolved. By this process two solutions are obtained:

first, the alkaline solution, of a deep orange-colour, which consists chiefly of the potash united to the oxide of osmium; second, the acid solution, of a deep red, which consists chiefly of the muriatic acid united to the oxide of *iridium.*

I. By evaporating this last solution to dryness, dissolving the residuum in water, and evaporating again, octahedral crystals are obtained, consisting of muriatic acid united to oxide of iridium. These crystals being dissolved in water, give a deep red solution, from which the iridium may be precipitated in the state of a black powder by putting into the liquid a plate of zinc or iron, or indeed any metal, except gold and platinum. When heat is applied to this powder it becomes white, and assumes the metallic lustre. In this state it is pure iridium. The metal may be obtained also by exposing the octahedral crystals to a strong heat. Some other processes for obtaining metallic iridium are given by Berzelius. But they are all difficult and tedious.

Properties. Iridium has the appearance of platinum, and seems to resist the action of heat at least as strongly as that metal; for neither the French chemists nor Mr. Tennant were able to fuse it. Vauquelin succeeded in fusing a little of it, and found it possessed of a certain degree of ductility.* Mr. Children succeeded in fusing it by means of his immense galvanic battery, and found its specific gravity 18·68.† As the globule was porous, it is obvious that this is considerably under the truth.

It resists the action of all acids, even the nitro-muriatic, almost completely; much more than three hundred parts being necessary of that acid to dissolve one of iridium.‡ Some attempts to take its specific gravity in my laboratory indicated it to be as high as 24·328; but the quantity weighed was so small that full reliance cannot be placed in the result. I infer from it, however, that it has a higher specific gravity than platinum.

Oxides. II. The affinity between iridium and oxygen seems to be considerable. When heated to incipient redness it combines with that principle; but it is again reduced to the metallic state by the application of a higher temperature. Berzelius has rendered it probable that it combines with four doses of oxygen, and forms four different oxides, though he has not succeeded in obtaining all these oxides in a separate state.

1. The protoxide may be obtained by boiling the protochloride with a concentrated solution of caustic potash. The protoxide

* Ann. de Chim. lxxxix. 240. † Phil. Trans. 1815, p. 370.
‡ Fourcroy and Vauquelin, Ann. de Chim. l. 22.

separates in the state of a *black* powder, which is scarcely acted on by acids, though it communicates to them a light-green colour. The alkaline ley becomes first *purple* and at last *blue*, owing, in the opinion of Berzelius, to the small portion of oxide held in solution, absorbing an additional quantity of oxygen. This protoxide may be obtained in the state of hydrate, by precipitating the protochloride of iridium with carbonate of potash. The hydrate is a bulky greenish-gray matter. An excess of carbonate of potash redissolves this precipitate. This hydrate dissolves in acids when assisted by heat, and forms salts of iridium.

From the analysis of several double chlorides of iridium, to be stated immediately, and made by Berzelius with great care, there is reason to believe that the atomic weight of iridium is 12·25. The protoxide of iridium is probably a compound of

1 atom iridium	. .	12·25
1 atom oxygen	. .	1
		13·25

2. *Sesquioxide of iridium* may be obtained by mixing the potassium-bichloride of iridium with its own weight of carbonate of potash, and heating the mixture in a close vessel to incipient ignition, taking care not to elevate the temperature too high, which would occasion the expulsion of the carbonic acid, and the combination of the oxide with the alkali. When the saline mass is dissolved in boiling water, and filtered, it leaves on the filter a blackish-blue powder, which is the sesquioxide. When washed with pure water it passes through the filter. It should therefore be washed with a solution of sal ammoniac, the last traces of which may be driven off by heat. In this state it is not soluble in acids. Hydrogen decomposes it without the aid of heat, and reduces it to the metallic state. When mixed with a combustible body, and heated, it is decomposed with a strong detonation.

When the sesquichloride of iridium is precipitated by an alkali, the sesquioxide generally falls in the state of a hydrate. It is then dark-brown and dissolves in acids forming salts, the solutions of which resemble a mixture of venous blood and water.

This oxide is also formed when metallic iridium is calcined with a mixture of potash and nitre. A dark brown matter is obtained, which dissolves in water, and communicates a fine dark yellowish-brown colour. In this compound the sesquioxide is

very easily changed into protoxide.   This sesquioxide has been
analyzed by Berzelius, and shown to be a compound of

1 atom iridium	. ".	12·25
•1½ atom oxygen	. .	1·5

13·75

3. *Binoxide.*   Berzelius has not been able to obtain this
oxide in a separate state, though analogy leaves little doubt of
its existence.   It would appear to possess acid characters ; for
it combines with alkalies, and cannot be separated from them by
acids.   From the analogy of the bichloride there is little doubt
that this oxide is a compound of

1 atom iridium	. .	12·25
˙2 atoms oxygen	. .	2

14·25

4. Teroxide of iridium is obtained by adding carbonate of potash
or soda to the red potassium chloride of iridium, free from ammo-
nia.   Scarcely any precipitate falls at first, but when digested, ·
a gelatinous hydrate falls, which, when collected on a filter, is
brownish-yellow or greenish, and so similar to the hydrated oxide
of rhodium, that it is impossible to distinguish them by their
appearance from each other.   This oxide dissolves in muriatic
acid, and when the solution is evaporated nearly to dryness it
becomes red.   This oxide has not been analyzed ; but from the
analogy of the terchloride of iridium, there can be no doubt that
it is a compound of

1 atom iridium	. .	12·25
3 atoms oxygen.	. .	3

15·25

5. Every body that has made experiments on iridium must
have remarked the blue coloured solutions which it yields, and
which Mr. Tennant ascribed to a peculiar oxide.   Berzelius is
of opinion that this blue oxide is a compound of the protoxide
and sesquioxide, though in what proportions has not been deter-
mined.   It is analogous to the blue oxides of tungsten and
molybdenum.

Chlorides.   III. Chlorine and iridium have a strong affinity for each other.
They combine in various proportions, as no fewer than four
different chlorides of iridium have been examined by Berzelius,
and which, from the analyses to which he subjected several of
them, appear to be composed as follows :

	Iridium.	Chlorine.
1. Chloride of	1 atom	+ 1 atom
2. Sesquichloride	1	+ 1½
3. Bichloride	1	+ 2
4. Terchloride	1	+ 3

1. *Bichloride.* This chloride has not yet been examined in a state of insulation, but it is easily obtained united with chloride of potassium. This double chloride is formed when iridium in fine powder is mixed with chloride of potassium, and heated to incipient redness in a stream of chlorine gas. The saline mass is separated by water from the metallic iridium, and aqua regia being added to the liquid, it is evaporated to dryness. The excess of chloride of potassium may be washed out by a little water, as the double chloride is insoluble in a solution of chloride of potassium. It may then be dissolved in boiling water containing a little aqua regia, and crystallized. The crystals are black, and constitute regular octahedrons. In powder it is red. It is insoluble in alcohol, and may be precipitated from its solution in water by the addition of that liquid. If pure it dissolves readily in water, but not if it contains an excess of chloride of potassium. The solution is red; but when spread thin it appears yellow. It bears an incipient red heat without alteration. In a strong red heat it is converted into a sesquichloride, and when the heat is still higher, chlorine and chloride of potassium are disengaged, and metallic iridium mixed with chloride of potassium remains. From the analysis of this double salt by Berzelius, it appears to be a compound of

1 atom chloride of potassium,
1 atom bichloride of iridium.

And the bichloride of iridium is composed of

2 atoms chlorine . . 9
1 atom iridium . . 12·25
_____
21·25

The potassium and ammonium bichlorides of iridium have the same figure and composition as the corresponding double chlorides of platinum; showing that iridium and platinum are isomorphous bodies.

2. *Sesquichloride of iridium.* This chloride may be obtained by heating iridium with a mixture of potash and nitre, and after having washed it with boiling water, digesting the remaining mass in muriatic acid which dissolves a great part of the matter, and assumes a blackish-brown colour. Evaporate the solution

to dryness, and digest the dry residue in alcohol, which dissolves the sesquichloride. It may be, obtained also by heating iridium in chlorine gas. Thus formed it is insoluble in water. And it becomes insoluble however obtained, if the solution be evaporated to dryness, and the residue be exposed to as high a temperature as it can bear without decomposition. The colour of the bichloride and that of the sesquichloride is very nearly the same, differing only in shade.

Potassium sesquichloride of iridium may be obtained by mixing iridium in fine powder with potassium bichloride of iridium, and heating the mixture in a glass retort to redness. No fusion takes place. The salt is to be dissolved in water to separate the uncombined iridium. On evaporating the solution a little potash bichloride of iridium first separates in crystals. The residual liquid being decanted off and slowly evaporated does not yield regular crystals. The salt is a dark yellowish-brown, with sometimes a shade of blue or green. It is almost insoluble in alcohol. Berzelius analyzed it, and obtained in two separate analyses

Chloride of potassium .	9·14 .	. 8·76
Chlorine . . .	6·75 .	. 6·75
Iridium . . .	9·14 .	. 8·76

It appears evident from these analyses that the atom of iridium was combined with $1\frac{1}{2}$ atom chlorine. The salts were not pure, nor from the mode of forming them could they be so. Hence the reason why the quantity of chloride of potassium was a little deficient. It is obvious also that there was a slight excess of chlorine in the first salt analyzed, and a still greater in the second. Still the analyses came near enough the truth to leave no doubt respecting the nature of the chloride of iridium contained in it.

3. *Chloride.* When iridium obtained by reducing the double chlorides by means of a stream of hydrogen gas, is exposed at an incipient red heat to a stream of chlorine gas, it swells up, and is converted into a light powder of an olive-green colour, and the additional weight corresponds to an atom of chlorine. The chloride formed therefore is a compound of

1 atom chlorine .	.	4·5
1 atom iridium .	.	12·25
		16·75

This chloride is insoluble in water.

Boiling muriatic acid dissolves a very little of it, and acquires a greenish colour. Aqua regia hardly acts upon it. But if we decompose it by potash, and then digest the oxide separated in muriatic acid, the chloride is again formed and dissolves in the excess of the muriatic acid. The colour of the solution is a mixture of brown, yellow, and green. When the solution is concentrated by evaporation it becomes yellow, and when evaporated to dryness it leaves a transparent yellow matter, which dissolves in a little hot water, but becomes muddy when much diluted. It seems to be a solution of chloride of iridium in muriatic acid. This chloride also combines with the alkaline chlorides, and forms double salts having a green colour.

4. *Terchloride of iridium.* This chloride has only been obtained in combination with chloride of potassium. When the ore composed of osmium and iridium, after fusion with nitre, has been treated with aqua regia and then dried, small quantities of water, cautiously added, dissolve out the excess of chloride of potassium; after this water digested on it acquires a rose-red colour. The first red solution being decanted off, and a little more water added, a new red solution may be obtained, and this may be repeated several times. But we must desist when ever the watery solution begins to assume a yellow colour. The red-coloured liquids being evaporated to dryness, and the dry mass being digested in alcohol of 0·84 to dissolve out the excess of chloride of potassium, a saline brown powder remains, which is a *potassium terchloride of iridium.* When dissolved in water, and subjected to spontaneous evaporation, this double chloride crystallizes in oblique four-sided prisms of a ruby-red colour, exactly similar in appearance to a salt of rhodium, though it does not contain a trace of that metal. This chloride was found by Berzelius composed of

Chlorine	.	.	..	12·379
Iridium	.	.	.	12·25
Chloride of potassium	.	.		26·58

As an atom of chloride of potassium weighs 9·5, it is obvious that the salt consists of 3 atoms of chloride of potassium united to one atom of a chloride of iridium, composed of 1 atom of iridium combined with 13·19 of chlorine, but 3 atoms of chlorine weigh 13·5. It is clear, therefore, that the chloride of iridium in the salt, is a compound of

3 atoms chlorine	13·5
1 atom iridium	12·25
	————
	25·75*

The deficiency both in the quantity of chlorine and chloride of potassium, may be owing either to an error in the number which we have chosen to denote an atom of iridium, or from impurities in the chloride subjected to analysis.

IV. No attempts have been made to unite iridium with bromine, iodine, hydrogen, azote, carbon, boron, silicon, or **Sulphurets.** phosphorus. It forms four different combinations with sulphur, for each of the chlorides is precipitated by sulphuretted hydrogen gas. Their colour is a very dark brown, almost black. While drying they are not converted into sulphates like sulphuret of platinum. They dissolve more easily in the hydrosulphurets than the sulphuret of platinum. When the sulphurets of iridium and platinum are mixed, nitric acid dissolves the former with a small quantity of the latter, and leaves sulphuret of platinum nearly pure. When any of the higher sulphurets of iridium are heated, sulphurous acid and sulphur are given out, and a gray sulphuret remains like that of lead, insoluble in nitric acid and scarcely in aqua regia. It is a protosulphuret, or a compound of an atom of each constituent.

V. The following are the results of Mr. Tennant's experiments to alloy iridium with the metals:

Alloys. "It does not combine with arsenic. Lead easily unites with it: but is separated by cupellation, leaving the iridium upon the cupel as a coarse black powder. Copper forms with it a very malleable alloy, which, after cupellation with the addition of lead, left a small proportion of the iridium, but much less than in the former case. Silver may be united with it, and the compound remains perfectly malleable. The iridium was not separated from it by cupellation, but occasioned on the surface a dark and tarnished hue. It appeared not to be perfectly combined with the silver, but merely diffused through the substance of it in the state of a fine powder. Gold alloyed with iridium is not freed from it by cupellation, nor by quartation with silver. The compound was malleable, and did not differ much in colour

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* The chloride which I analyzed, and of which I have given an account in my " First Principles," p. 475, was obviously this terchloride ; and if the quantity of chlorine which was driven off by ignition be taken into consideration, my analysis comes very near the result stated in the text.

from pure gold; though the proportion of alloy was very con-
siderable. If the gold or silver is dissolved, the iridium is left
in the form of a black powder."*

Vauquelin alloyed this metal with lead, copper, and tin. All
these alloys were malleable, and the hardness of the different
metals was greatly increased by the addition of the iridium.†

SECTION VI.—OF OSMIUM.

This metal is always found combined with iridium, and was
discovered by Mr. Tennant by the process described in the last
section. If three parts by weight of the pulverulent ore of
iridium be well mixed with 1 part of nitre and put into a cold
crucible, and the crucible be raised in the open fire to a good
red heat, until the ingredients are reduced to a pasty state,
fumes of oxide of osmium will be found to arise from it. The
soluble parts of the mixture are then to be dissolved in the
smallest quantity of water necessary for the purpose, and the
liquid thus obtained is to be mixed in a retort with so much
sulphuric acid (diluted with its own weight of water) as is
equivalent to the potash contained in the nitre employed; but
no inconvenience will result from the use of an excess of sul-
phuric acid. By distilling rapidly into a clean receiver for so
long a time as the osmic fumes continue to come over, the
oxide will be collected in the form of a white crust on the sides
of the receiver, and there melting it will run down in drops
beneath the watery solution, forming a fluid flattened globule
at the bottom. When the receiver has become quite cold, the
oxide will become solid and crystallize.‡

When the ore of iridium in fine powder is fused with
an alkali, and the fused mass is acted on by muriatic and
nitric acids, distilled oxide of osmium passes over. The nitric
acid decomposes the double chloride; and this action is the
more complete the smaller the quantity of muriatic acid em-
ployed. The distillation is to be continued at a heat below

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* See Mr. Tennant's paper on Two Metals found in the Powder remaining
after the Solution of Platina, Phil. Trans. 1804. Descotils did not succeed
in obtaining it in a separate state; but he showed that the red colour which
the precipitates of platinum sometimes assume is owing to the presence of
iridium. See his paper, Ann. de Chim. xlviii. 153. Fourcroy and Vauque-
lin confounded together the properties of osmium and iridium, ascribing both
to one metal; to which they have given the name of *ptene*. See Ann. de
Chim. xlix. 177, and l. 5. See also Berzelius's paper in the Kong. Vet.
Acad. Handl. 1828, p. 52.

† Ann de Chim. lxxxix. 237.   ‡ Wollaston; Phil. Trans. 1829, p. 8.

boiling till a fourth part of the liquid has passed over. We must then remove the receiver, otherwise the osmium becomes mixed with iridium. To obtain the osmium from the liquor in the receiver, the best way is to employ mercury after having added to the liquid as much muriatic acid as will be sufficient to convert the mercury into chloride. A portion of the osmium still remains in solution. To obtain it saturate the liquid with ammonia, evaporate to dryness, and heat the dry residue in a retort. Metallic osmium remains, while the mercury sublimes in combination with the sal ammoniac.

The precipitate obtained by the mercury consists of chloride of mercury, an amalgam of osmium, and running mercury slightly alloyed with osmium. If we put it into a glass tube blown into a ball, and pass a current of dry hydrogen gas over it while heated by a spirit lamp, mercury and chloride of mercury sublimes, and metallic osmium remains behind. It has the form of a black powder, which acquires the metallic lustre when burnished. To obtain it in a compact mass, let the oxide be volatilized along with a current of dry hydrogen gas, and made to pass through an inch of glass tube heated to redness. A kind of combustion takes place, and the osmium forms in the hot part of the tube a compact metallic ring.*

Properties. I. Osmium obtained in this way has a strong metallic lustre, and a white colour resembling that of ore of iridium. Its specific gravity is 10. It dissolves slowly in nitric acid. In aqua regia it dissolves rapidly, and so does it in fuming nitric acid when assisted by heat. When in a state of great division, it takes fire and burns at a red heat. When in a compact state, the oxidizement goes on very slowly. This metal is not altered by exposure to the air at the common temperature.

Berzelius has shown by a careful analysis of the potassium bichloride of osmium, that the atomic weight of this metal is very nearly 12·5.

II. From the experiments of Berzelius it appears probable that osmium unites with 5 different doses of oxygen, and forms 5 different oxides; though two of these have not yet been obtained in a separate state.

Oxides. 1. *Oxide.* It may be obtained by treating the potassium chloride of osmium with caustic potash. The solution does not become muddy immediately; but in a few hours a deposite of the hydrated oxide falls of a very deep-green colour, indeed

* Berzelius; Kongl. Vetens. Acad. Handl. 1828, p. 80.

almost black. The alkali still keeps a portion in solution, which gives the liquid a green colour; and the hydrate contains a portion of potash which cannot be removed by washing. It dissolves slowly in acids, communicating a blackish green colour like the salts of iridium. Nitric acid dissolves it without the application of heat, and when evaporated to dryness leaves a greenish-coloured transparent varnish. The sulphate becomes almost black when dried. The phosphate has the same colour, and is soluble with difficulty. Muriatic acid dissolves it, and assumes a deep greenish-brown colour. When the hydrate is heated in a close vessel it gives out water, but does not sublime. It detonates with combustibles. It is composed of

1 atom osmium	. .	12·5
1 atom oxygen	. .	1
		13·5

2. *Sesquoxide.* This oxide has not been examined. Berzelius considers the deep-blue powder from osmium to be a compound of the oxide and sesquoxide. But no evidence has been adduced in support of this opinion. The sesquoxide, supposing it to exist, is a compound of

1 atom osmium	. .	12·5
1½ atom oxygen	. .	1·5
		14

3. *Binoxide.* This oxide may be obtained by treating a saturated solution of potassium bichloride of osmium with carbonate of soda. At first the liquid appears unaltered, but after some time it becomes muddy and black, and allows the hydrated binoxide to fall. Collected on a filter it appears black, and contains alkali, which cannot be removed by washing; but dilute muriatic acid carries it off without attacking the oxide. When this oxide is dried on the water-bath, and then heated in carbonic acid, it gives out water and then a little of the volatile oxide. But the oxide that remains after exposure to a red heat is still the binoxide. When thus obtained it is not soluble in acids. Muriatic acid when long boiled on it, assumes a yellowish tint. Yet it is capable of combining with acids, and of forming a peculiar class of salts. This oxide is composed of

1 atom osmium	. .	12·5
2 atoms oxygen	. .	2
		14·5

4. *Quateroxide*. By this name the volatile oxide of osmium may be called, because it contains 4 atoms of oxygen. It is obtained when osmium is burnt, or when we treat with hot nitric acid either the double chlorides or the oxides of osmium. An easy process for procuring it has been given at the beginning of this section. If we heat osmium to redness in a ball blown in a barometer tube, and cause a current of oxygen gas to pass over it, the osmium burns, and the quateroxide is deposited at some distance in the tube. It is deposited in white brilliant crystals; sometimes it has a tint of yellow. It is often liquid at first, and on cooling assumes the form of a crystalline mass. It dissolves very slowly in water; it may be kept melted a long time in that liquid without disappearing. The solution is colourless. It dissolves readily in alcohol and ether; but it is reduced in the solution, and in 24 hours is deposited in the metallic state. Alcohol and ether added to the aqueous solution, occasion neither precipitation nor reduction. Tallow, fat oils, and similar bodies, reduce this oxide. If we rub the stopper of a bottle containing the aqueous solution of quateroxide of osmium with hog's lard, it becomes black from reduced osmium in a few hours. It may be volatilized in hydrogen gas without reduction. But when a mixture of the vapour of this oxide and hydrogen gas is passed through a red-hot tube, the osmium is reduced. Sulphuretted hydrogen gas reduces it without the action of heat being necessary. The oxide becomes hot of itself, melts, and is volatilized. so that the sides of the vessel are covered with sulphuret of osmium.

The smell of this oxide is strong and quite peculiar, and affords therefore an excellent character to enable us to recognise the presence of osmium. If a little of it be placed upon the edge of a platinum foil, and brought so near the flame of a spirit-of-wine lamp as to heat the osmium, the part of the flame which rises above the foil becomes bright near the osmium as if olefiant gas were burning.

From an experiment by Berzelius, it appears that 0·275 gramme of osmium when burnt in oxygen gas unite with 0·09 of oxygen, so that 12·5 of osmium would combine with 4·09 oxygen. It is obvious from this that the volatile oxide of osmium is a quateroxide.

5. When gallic acid is dropt into the aqueous solution of quateroxide of osmium, the liquid gradually assumes a deep-*blue* colour: and in various processes, Berzelius obtained a blue sublimate. These colours are owing to the formation of *blue*

oxide of osmium, which Berzelius considers as a compound of oxide and sesquoxide. But he has produced no fact in support of this opinion, except the analogy of the *blue oxide of iridium*.

III. Osmium unites in as many proportions with chlorine as it does with oxygen, and forms as many chlorides. These hitherto have been only examined by Berzelius.

1. Chloride. When chlorine gas is passed over osmium at the ordinary temperature of the atmosphere, there is no apparent action; but if we heat the metal, there instantly rises from it a beautiful dark-green sublimate, which is the *chloride of osmium*. If we continue the passage of chlorine gas and the heat, a red pulverulent sublimate gradually makes its appearance, which is the *bichloride of osmium*. If the chlorine gas be moist the bichloride becomes yellow, and gradually crystallizes. When the bichloride is dissolved in water, it assumes a yellow colour. On adding a new portion of water the colour changes to green, and the smell of volatile oxide becomes apparent. Soon after this the colour deepens, and a light-blue flocky precipitate of metallic osmium is deposited. We see from this that the bichloride is decomposed by water into muriatic acid, quateroxide, and metallic osmium. It is easy to see that two atoms of bichloride, which are composed of

<div align="center">

2 atoms osmium,
4 atoms chlorine,

</div>

are converted by decomposing four atoms of water into

<div align="center">

4 atoms muriatic acid,
1 atom quateroxide,
1 atom metallic osmium.

</div>

The chloride undergoes the very same decomposition when mixed with water.

Both of these chlorides have the property of combining with chloride of potassium, and forming with it a double salt. But the first undergoes decomposition, and deposites osmium when treated with alcohol. The potassium bichloride may be formed by mixing metallic osmium with chloride of potassium, and passing chlorine over the mixture when raised to a red heat. The chlorine is slowly absorbed, and a red powder is obtained which is the double bichloride in question. When dissolved in water the solution has a yellow colour. By evaporation it yields octahedral crystals of a brown colour.

2. The sesquichloride and terchloride of osmium have not been obtained in a separate state, but Berzelius has formed two double chlorides which he considers as containing them, united

to sal ammoniac.   The method of proceeding was this : A current of oxygen gas was passed over a mixture of iridium and osmium, heated in a glass tube, and the excess of gas was received in a dilute solution of ammonia, which, at the end of the process, was saturated with oxide of osmium.   The ammoniacal liquid was mixed with an excess of muriatic acid and a little mercury, and frequently agitated during 48 hours.   When the smell of oxide of osmium was no longer perceptible, the whole was filtered.   The colour of the liquid was purple brown, and when evaporated to dryness it left a dark brown salt.   This salt dissolves in alcohol with a beautiful purple colour similar to that of manganesiate of potash. · A salt is left insoluble in that liquid.   It dissolves in water, and the solution has a purple brown colour.   Berzelius considers the first of these salts as a combination of terchloride of osmium with sal ammoniac, and the second as a combination of sesquichloride with the same salt.

From a comparison of the chlorides of iridium and osmium it is evident that there is a striking analogy between them.   Indeed iridium and osmium seem to be isomorphous bodies.   No chloride of osmium proportional to the quateroxide has been hitherto observed ; but analogy would lead us to expect that such a chloride is likely to exist.

IV. Nothing is known respecting the combinations which osmium may form with bromine, iodine, hydrogen, azote, carbon, boron, silicon, and phosphorus.

Sulphurets.   V. It has a strong affinity for sulphur, and combines with as many proportions of that body as it does with chlorine.   For sulphuretted hydrogen gas throws it down from all its solutions.   Even the double chlorides are thrown down by means of it.   The red solutions are not thrown down so easily as the rest.   But when the red solutions saturated with sulphuretted hydrogen are left in a well-corked phial, a yellowish-brown precipitate gradually falls.   The solution of the binoxide of osmium is precipitated by sulphuretted hydrogen black, with a shade of brown.

Hydrogen gas when passed over the sulphurets of osmium, heated to redness, decomposes them with difficulty, sulphuretted hydrogen gas being evolved.   A portion of sulphuret decomposed in this way, by Berzelius, was found to be composed of

Osmium   .   .   12·5
Sulphur   .   .   4·975

This is obviously 1 atom of osmium, and $2\frac{1}{2}$ atoms sulphur. Hence the sulphuret was doubtless a mixture or compound of

1 atom bisulphuret of osmium,

1 atom tersulphuret of osmium.

Sulphuret of osmium obtained in the moist way, dissolves in nitric acid as easily as sulphuret of iridium, and is converted into sulphate, which is not precipitated by alkalies or their carbonates.

VI. The remaining compounds of this remarkable metal Alloys. remain still almost unknown. Mr. Tennant showed that it formed an amalgam with mercury. Heated with copper and with gold in a charcoal crucible, it melted with each of these metals forming alloys which were quite malleable. These compounds were easily dissolved in aqua regia, and by distillation afforded volatile oxide of osmium distinguished by its usual properties.

APPENDIX.

1. VANADIUM, *a new metal.*

SINCE the chapter, giving an account of the acidifiable bases, in the first volume of this work, was written, a new metal has been discovered by Mr. N. G. Sefström, to which he has given the name of *Vanadium*, from Vanadis, an appellation of Freya, the principal female deity of ancient Scandinavia.

Rinmann had given a method of detecting cold short iron, which was this: when such iron is dissolved in muriatic acid, it deposites a black powder. Mr. Sefström had examined, in this way, an iron which was not cold short, and finally, the iron of Eckersholm, and found to his great surprise, that both yielded a black powder; though the Taberg iron is reckoned the toughest, and best in Sweden. On examining the black powder, he found that it con-tained silica, iron, alumina, lime, copper, cobalt, and a substance similar, in some respects, to chromium, and in others, to uranium. A comparative set of experiments satisfied him that it was not the former, nor did it agree in its characters with uranium; it was, therefore, a new substance.

The iron yielded it in very minute quantity, so that he obtained at first only about $\frac{1}{5}$d of a grain. This induced him to examine the scoriæ from the forge, where the iron had been smelted. From this he obtained enough to enable him to determine its properties. His mode of extracting it from these scoriæ was as follows: The scoriæ were pulverized, till they were fine enough to pass through a common sieve. They could not be made fine, because they con-tained grains of iron. To get rid of this obstruction, they were moistened with water, in a porcelain dish, and then enough of fuming nitric acid was added to oxidize the iron. The porce-lain dish was then put upon the sand bath, and stirred constantly, till the action was at an end. It is then dried, heated to redness, and reduced to a very fine powder; and, after being washed, is collected on the filter. Mix every three parts of these washed scoriæ with two parts of saltpetre, and one part of carbonate of

soda, and expose the mixture for four hours to a strong red heat, in a covered vessel of iron. A solid matter is obtained, having a compact and homogeneous appearance. Reduce it to powder, and boil it several times in water, in a silver vessel. Saturate the filtered liquid, as exactly as possible, with nitric acid, (previously deprived of its nitrous gas by boiling.) In general, silica only precipitates. Should the precipitate have a brick-red colour, indicating the presence of venadic acid, it must be moistened with caustic ammonia, and then digested in boiling water.

The filtered liquid being neutralized, the venadic acid is thrown down by acetate or nitrate of lead Collect the precipitate on a filter, and wash it. After having deprived it of water by pressure, moisten it with muriatic acid, and shake it occasionally. Then add alcohol, and keep the mixture for some time in a temperature nearly as high as that of boiling water. The solution has a blue colour, from the chloride of vanadium which it contains. It contains also phosphoric acid, alumina, and zirconia. Let it be evaporated in a retort; dissolve the residue in water, and treat it with nitric acid to convert oxide of vanadium into vanadic acid. Saturate this acid with carbonate of potash, and heat in a platinum crucible till the whole is brought to complete fusion. Dissolve the fused mass in as little water as possible, and put a piece of sal ammoniac into the solution. Vanadiate of ammonia is formed, which precipitates. Collect the precipitate on a filter, and wash it with a solution of sal ammoniac, in order to separate the phosphoric acid. Then wash off the sal ammoniac by alcohol.

When vanadiate of ammonia is heated in the open air, the ammonia is driven off, and vanadic acid remains; and, when heated in an atmosphere of carbonic acid gas, it leaves oxide of vanadium,—both in a state of as great purity as they can be obtained.

Chromium, molybdenum, and tungsten, are the substances to which vanadium has the greatest resemblance.

To chromium it has a strong analogy. Both give the same shade of green to fluxes before the blow-pipe. Both form red coloured acids, the salts of which are yellow, and whose solutions, mixed with acids, become deep red. But they differ in this, that the liquid containing chromic acid preserves its red colour when evaporated, while vanadic acid either becomes colourless by heat, or deposites vanadic acid in the form of a deep red powder.

The oxide of chromium is green, and insoluble in alkalies; and, when heated, becomes of a very deep green, does not absorb oxygen, and is insoluble in water, and almost in acids.—Vanadium gives also a green oxide; but it is soluble in water and in alkalies. When heated, it melts and absorbs oxygen, and the fused mass is soluble in water.

Chromic acid loses oxygen when heated, and is converted into oxide. Vanadic acid begins by fusing into a deep orange red liquid, which, at a higher temperature, loses a portion of its oxygen.

The only circumstance in which vanadium resembles molybdenum is, in the blue colour of certain of its combinations. But these compounds are easily distinguished from the blue combinations of molybdenum; for the latter, treated by small portions at a time by potash, lose their colour, and allow the red hydrate of the oxide of molybdenum to precipitate, while the liquid becomes colourless. On the other hand, the alkalies precipitate from the blue salts of vanadium an oxide of a light gray colour, and if the alkali be in excess, the supernatant liquid is brown or green, according to the degree of oxidizement.

The analogy between vanadium and tungsten is still less. The blue combinations of that metal have no stability, its oxides do not combine with the acids, its acid is pale yellow, and the salts which it forms with the alkaline bases are colourless.*

Wöhler has already found vanadium in the brown lead ore of Zimapan in Mexico. It was in this mineral that Del Rio thought he had discovered a new metal—an opinion, which was called in question by Collet-Descotils, and afterwards by Del Rio himself. I have been told also, that Mr. Johnstone has obtained vanadium from a specimen of lead ore, from Wanlockhead. This specimen was considered as arseniate of lead, with the external characters of which it perfectly agrees. It consisted of small mamillary globules on the surface of quartz, covered externally with a whitish powder. The fracture of the specimen is described as crystalline; the lustre is waxy, and the colour light yellow, scratched by the knife. It is said, like arseniate of lead, to crystallize in six-sided prisms. The specific gravity is said also to be nearly the same as that of arseniate of lead. The principal differences between vanadiate and arseniate of lead, lies in the lustre.

* Ann. de Chim. et de Phys. xlvi. 105.

TABLE I.

SPECIFIC GRAVITY OF THE GASES.

Names of Gases.	Specific gravity at 60°.	Weight of 100 cubic inches in grains.
Air	1·	31·1446
Hydrogen . .. .. . '	0·0694	2·1614
Carburetted hydrogen . .	0·5555	17·3025
Ammonia . '. . . .	0·59027	18·3837
Carbonic oxide	0·9722	30·2794
Azotic gas	0·9722	30·2794
Olefiant gas	0·9722	30·2794
Deutoxide of azote . . .	1·0416	32·4402
Oxygen	1·1111	34·6048
Sulphide of hydrogen . .	1·1805	36·6816
Sesquisulphuret of phosphorus .	1.21527	37·8491
Muriatic acid	1·28472	40·0121
Carbonic acid	1·5277	47·4691
Protoxide of azote . . .	1·5277	47·4691
Phosphuretted hydrogen . .	1·77088	55·1534
Cyanogen	1·8055	56·2316
Sulphurous acid . . .	2·2222	69·2066
Fluo-boric acid . . .	2·3611	73·5355
Protoxide of chlorine . . .	2·4444	76·1300
Chlorine	2·5	77·8615
Arseniated hydrogen . . .	2·79305	86·9884
Chloro carbonic acid . . .	3·4722	108·1400
Fluo-silicic acid	3·6111	112·4700
Hydriodic acid	4·34027	135·1760

2. SPECIFIC GRAVITY OF VAPOURS.

Vapours.	Specific gravity at 60°.	Weight of 100 cubic inches at 60° in gr.
Air	1·000	31·1446
Steam	0·481	14·9806
Hydrocyanic acid vapour . .	0·912	28·4039
Alcohol	1·311	40·8306
Muriatic ether	2·255	70·2311
Bisulphide of carbon . . .	2·376	73·9996
Sulphuric ether	2·415	75·2142
Oil of turpentine . . .	3·342	99·4006

Vapours.	Specific gravity at 60°.	Weight of 100 cubic inches at 60° in gr.
Hydriodic ether . . .	4·666	145·3200
Chloride of silicon . . .	6·111	190·3250
Sesqui-chloride of arsenic . .	6·488	202·066
Carbon	0·4166	13·0048
Phosphorus	1·1111	34·6048
Sulphur	1·1111	34·6048
Arsenic	2·6988	84·0531
Mercury	6·975	217·234

TABLE II.

EXHIBITING THE ATOMIC WEIGHTS OF BODIES.

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hydr. = 1.
Hydrogen	0·125	1
Carbon	0·75	6
Lithium	0·75	6
Carbo-hydrogen . . .	0·875	7
Oxygen	1	8
Boron	1	8
Silicon	1	8
Carburetted hydrogen . .	1	8
Water	1·125	9
Silicet of hydrogen . .	1·125	9
Aluminum	1·25	10
Magnesium	1·5	12
Bicarburet of hydrogen .	1·625	13
Azote	1·75	14
Carbonic oxide . . .	1·75	14
Olefiant gas . . .	1·75	14
Lithia	1·75	14
Silicet of carbon . .	1·75	14
Phosphorus	2	16
Sulphur	2	16
Silica	2	16
Deutoxide of hydrogen .	2·125	17
Ammonia	2·125	17
Sulphide of hydrogen .	2·125	17
Sesqui-hydret of phosphorus .	2·1875	17·5
Fluorine	2·25	18
Glucinum	2·25	18
Ammonium? . . .	2·25	18
Alumina	2·25	18
Hydro-fluoric acid . .	2·375	19
Calcium	2·5	20
Magnesia	2·5	20
Trito-carbo-hydrogen .	2·625	21

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hydr = 1.
Zirconium	2·75	22
Protoxide of azote	2·75	22
Carbonic acid	2·75	22
Carburet of phosphorus . . .	2·75	22
Sulphuret of lithium	2·75	22
Alcohol	2·85	23
Sodium	3	24
Boracic acid	3	24
Sulphuret of boron	3	24
Sulphuret of silicon	3·24	24
Hydrate of silica	3·125	25
Glucina	3·25	26
Titanium	3·25	26
Cyanogen	3·25	26
Nickel	3·25	26
Cobalt	3·25	26
Fluo-silicic acid	3·25	26
Hydrate of alumina . . .	3·375	27
Hydro-cyanic acid	3·375	27
Phosphuretted hydrogen . . .	3·375	27
Iron	3·5	28
Manganese	3·5	28
Sulphuret of magnesium . . .	3·5	28
Tetarto-carbo-hydrogen . . .	3·5	28
Lime	3·5	28
Phosphorous acid	3·5	28
Zirconia	3·75	30
Deutoxide of azote	3·75	30
Sesqui-fluo-silicic acid . . .	3·875	31
Sulphurous acid	4	32
Copper	4	32
Tellurium	4	32
Chromium	4	32
Suboxide of manganese . . .	4	32
Soda	4	32
Telluretted hydrogen . . .	4·125	33
Bisulphide of hydrogen . . .	4·125	33
Zinc	4·25	34
Fluo-boric acid	4·25	34
Protoxide of nickel . . .	4·25	34
Protoxide of cobalt . . .	4·25	34
Chlorine	4·5	36
Peroxide of sodium . . .	4·5	36
Phosphoric acid	4·5	36
Peroxide of calcium . . .	4·5	36
Protoxide of iron	4·5	36
Sulphuret of calcium . . .	4·5	36
Protoxide of manganese . . .	4·5	36
Yttrium	4·5	36
Bihydrate of alumina . . .	4·5	36
Oxalic acid	4·5	36

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hydr. = 1
Muriatic acid	4·625	37
Formic acid	4·625	37
Sulphuric ether	4·625	37
Hyponitrous acid	4·75	38
Sesqui-oxide of nickel	4·75	38
Sesqui-oxide of cobalt	4·75	38
Arsenic	4·75	38
Bisulphide of carbon	4·75	38
Arsenietted hydrogen	4·9375	39·5
Sesqui-phosphuret of sulphur	5	40
Potassium	5	40
Protoxide of chromium	5	40
Sesqui-oxide of manganese	5	40
Peroxide of iron	5	40
Sulphuret of sodium	5	40
Sulphuric acid	5	40
Hypo-sulphurous acid	5	40
Oxide of copper	5	40
Oxide of tellurium	5	40
Selenium	5	40
Dihydrate of silica	5·125	41
Selenietted hydrogen	5·125	41
Chloride of carbon	5·25	42
Hexa-carbo-hydrogen	5·25	42
Titanic acid	5·25	42
Oxide of zinc	5·25	42
Sulphuret of nickel	5·25	42
Sulphuret of cobalt	5·25	42
Peroxide of cobalt	5·25	42
Chloride of lithium	5·25	42
Hypophosphorous acid	5·5	44
Strontium	5·5	44
Chloride of silicon	5·5	44
Binoxide of manganese	5·5	44
Protoxide of chlorine	5·5	44
Yttria	5·5	44
Sulphuret of iron	5·5	44
Sulphuret of manganese	5·5	44
Nitrous acid	5·75	46
Biphosphuret of sulphur	6	48
Dichloride of carbon	6	48
Manganesic acid	6	48
Molybdenum	6	48
Potash	6	48
Oxide of selenium	6	48
Phosphuret of chromium	6	48
Sulphuret of chromium	6	48
Phosphuret of copper	6	48
Sulphuret of copper	6	48
Chloride of magnesium	6	48
Proto-hydrated sulphuric acid	6·125	49

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hydr. = 1
Perhydrate of iron	6·25	49
Hydro-carburet of chlorine . . .	6·25	50
Sulphuret of zinc	6·25	50
Arsenious acid	6·25	50
Acetic acid	6·25	50
Succinic acid	6·25	50
Chloro-carbonic acid	6·25	50
Sesqui-sulphuret of titanium . . .	6·25	50
Strontian	6·5	52
Mellitic acid	6·5?	52?
Sesqui-sulphuret of iron . . .	6·5	52
Chromic acid	6·5	52
Protoxide of cerium	6·5	52
Chloride of sulphur	6·5	52
Chloride of phosphorus . . .	6·5	52
Bisulphuret of calcium . . .	6·5	52
Palladium	6·75	54
Rhodium	6·75	54
Nitric acid	6·75	54
Sulphuret of arsenic	6·75	54
Cadmium	7	56
Protoxide of molybdenum . .	7	56
Peroxide of cerium	7	56
Sulphuret of potassium . . .	7	56
Chloride of calcium	7	56
Selenious acid	7	56
Tris-hydrate of silica . . .	7·125	57
Arsenic acid	7·25	58
Bisulphuret of cobalt . . .	7·25	58
Tin	7·25	58
Sesqui-sulphuret of arsenic . .	7·25	58
Citric acid	7·25	58
Acetic acid crystals	7·375	59
Sesqui-chloride of carbon . . .	7·5	60
Chloride of sodium	7·5	60
Peroxide of strontium . . .	7·5	60
Bisulphuret of iron	7·5	60
Sulphuret of strontium . . .	7·5	60
Teroxide of chlorine . . .	7·5	60
Thorium	7·5	60
Sesquisulphuret of arsenic . .	7·75	62
Chloride of nickel	7·75	62
Chloride of cobalt	7·75	62
Oxide of palladium	7·75	62
Protoxide of rhodium . . .	7·75	62
Chloro-cyanic acid	7·75	62
Croconic acid	7·75	62
Antimony	8	64
Selenic acid	8	64
Peroxide of potassium . . .	8	64
Chloride of iron	8	64

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hydr. = 1.
Chloride of manganese	8	64
Sesquisulphuret of selenium	8	64
Bisulphuret of copper	8	64
Binoxide of molybdenum	8	64
Gallic acid	8	64
Sesquifluoride of arsenic	8·125	65
Protoxide of tin	8·25	66
Peroxide of rhodium	8·25	66
Tartaric acid	8·25	66
Vinic acid	8·25	66
Barium	8·5	68
Thorina	8·5	68
Dichloride of sulphur	8·5	68
Chloride of tellurium	8·5	68
Chloride of copper	8·5	68
Disulphuret of nickel	8·5	68
Quateroxide of chlorine	8·5	68
Sesquichloride of phosphorus	8·75	70
Chloride of zinc	8·75	70
Tannin	8·75?	70?
Bismuth	9	72
Molybdic acid	9	72
Uric acid	9	72
Disulphuret of iron	9	72
Suboxide of copper	9	72
Bisulphuret of potassium	9	72
Sulphuret of cadmium	9	72
Hyposulphuric acid	9	72
Perfluoride of manganese	9·125	73
Peroxide of tin	9·25	74
Sulphuret of tin	9·25	74
Tartaric acid crystals	9·375	75
Oxide of antimony	9·5	76
Chloride of selenium	9·5	76
Dichloride of calcium	9·5	76
Citric acid crystals	9·5	76
Chloric acid	9·5	76
Chloride of potassium	9·5	76
Barytes	9·5	76
Sulphide of arsenic	9·75	78
Selenite of arsenic	9·75	78
Bromine	10	80
Antimonious acid	10	80
Oxide of bismuth	10	80
Bisulphide of molybdenum	10	80
Disulphuret of copper	10	80
Chloride of strontium	10	80
Hydrobromic acid	10·125	81
Sesquichloride of iron	10·25	82
Sesquisulphuret of tin	10·25	82
Antimonic acid	10·5	84

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hyd). = 1.
Chloride of molybdenum	10·5	84
Phosphuret of barium	10·5	84
Sulphuret of barium	10·5	84
Bihoxide of barium	10·5	84
Sulphuret of bismuth . . .	11	88
Tersulphuret of potassium . . .	11	88
Sesquisulphide of antimony . . .	11	88
Chloro-chromic acid	11	88
Fuming sulphuric acid	11·125	89
Bisulphuret of tin	11·25	90
Black cast iron	11·25	90
Uric acid crystals	11·25	90
Sesquifluoride of antimony . . .	11·375	91
Sesquichloride of arsenic	11·5	92
Sulpho-chromic acid	11·5	92
Perchloric acid	11·5	92
Chloride of cadmium	11·5	92
Chloride of tin	11·75	94
Bisulphide of antimony	12	96
Tersulphide of molybdenum . . .	12	96
Bromide of sulphur	12	96
Platinum	12	96
Iridium	12·25	98
Bichloride of titanium . . .	12·25	98
Mercury	12·5	100
Gold	12·5	100
Tungsten	12·5	100
Osmium	12·5	100
Dichloride of copper . .	12·5	100
Quintosulphuret of calcium . . .	12·5	100
Naphthaline	12·5	100
Lead	13	104
Protoxide of platinum . . .	13	104
Quatersulphuret of potassium . . .	13	104
Persulphide of antimony	13	104
Chloride of barium	13	104
Mucic acid	13	104
Persulphuret of bismuth . . .	13	104
Oxide of iridium	13·25	106
Oxide of mercury	13·5	108
Oxide of gold	13·5	108
Bromide of iron	13·5	108
Chloride of bismuth	13·5	108
Camphoric acid	13·5	108
Silver	13·75	110
Oxychloride of sulphide of carbon . .	13·75	110
Protoxide of lead	14	112
Peroxide of platinum	14	112
Sulphuret of platinum	14	112
Sesquioxide of gold	14	112
Bichloride of selenium	14	112

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hydr. = 1
Trisphosphuret of copper	14	112
Quatersulphide of molybdenum . . .	14	112
Quintosulphuret of copper . . .	14	112
Hydrosulphurous acid . . .	14·375	115
Sulphuret of mercury	14·5	116
Sesquioxide of lead	14·5	116
Oxide of silver	14·75	118
White cast iron . . .	14·75	118
Sesquichloride of antimony . . .	14·75	118
Perchloride of manganese . . .	14·75	118
Bromide of potassium . . .	15	120
Peroxide of lead . . .	15	120
Sulphuret of lead . . .	15	120
Bichloride of molybdenum . . .	15	120
Sesquisulphide of platinum . . .	15	120
Quintosulphuret of potassium . . .	15	120
Benzoic acid	15	120
Bichloride of tin	15·25	122
Tungstic acid	15·5	124
Perchloride of phosphorus . . .	15·5	124
Sesquisulphide of gold . . .	15·5	124
Tetra-sulphuret of iron . . .	16	128
Bisulphide of platinum . . .	16	128
Bromide of tin	16·25	130
Bisulphide of tungsten . . .	16·5	132
Iodide of carbon	16·5	132
Chloride of platinum . . .	16·5	132
Chloride of mercury . . .	17	136
Chloride of gold	17	136
Sesqui-bromide of phosphorus . . .	17	136
Chloride of lead . . .	17·5	140
Hydro-carburet of iodine . . .	17·5	140
Iodide of sulphur	17·75	142
Iodide of phosphorus . . .	17·75	142
Iodide of calcium . . .	18·25	146
Chloride of silver . . .	18·25	146
Quinto-sulphuret of barium . . .	18·5	148
Tersulphide of tungsten . . .	18·5	148
Iodide of sodium . . .	18·75	150
Dichloride of tin	19	152
Bichloride of bromium . . .	19	152
Iodide of iron	19·25	154
Perchloride of antimony . . .	19·25	154
Sesqui-chloride of gold . . .	19·25	154
Terchloride of molybdenum . . .	19·5	156
Sesqui-bromide of arsenic . . .	19·75	158
Quater-chloride of azote . . .	19·75	158
Iodide of zinc	20	160
Iodic acid	20·75	166
Iodide of potassium . . .	20·75	166
Bichloride of platinum . . .	21	168

				ATOMIC WEIGHTS.	
				Oxygen = 1.	Hydr. = 1.
Iodide of strontium	.	.	.	21·25	170
Bichloride of tungsten	.	.	.	21·5	172
Suboxide of silver	.	.	.	21·625	173
Bromide of mercury	.	.	.	22·5	180
Columbium	.	.	.	22·75	182
Persulphide of arsenic	.	.	.	22·75	182
Iodide of cadmium	.	.	.	22·75	182
Iodide of tin	.	.	.	23	184
Sesqui-bromide of antimony	.	.	.	23	184
Bromide of lead	.	.	.	23	184
Bromide of silver	.	.	.	23·75	190
Iodide of barium	.	.	.	24·25	194
Sesquiodide of carbon	.	.	.	24·375	195
Carbazotic acid	.	.	.	24·5	196
Iodide of bismuth	.	.	.	24·75	198
Chloriodic acid	.	.	.	24·75	198
Suboxide of platinum	.	.	.	25	200
Bibromide of selenium	.	.	.	25	200
Sesquiodide of phosphorus	.	.	.	25·625	205
Columbic acid	.	.	.	25·75	206
Terchloride of tungsten	.	.	.	26	208
Uranium	.	.	.	26	208
Dioxide of gold	.	.	.	26	208
Perbromide of phosphorus	.	.	.	27	216
Disulphuret of mercury	.	.	.	27	216
Protoxide of uranium	.	.	.	27	216
Bibromide of tin	.	.	.	27·25	218
Peroxide of uranium	.	.	.	28	224
Sulphuret of uranium	.	.	.	28	224
Disulphuret of lead	.	.	.	28	224
Iodide of mercury	.	.	.	28·25	226
Sesquiodide of arsenic	.	.	.	28·375	227
Iodide of lead	.	.	.	28·75	230
Tersulphide of columbium	.	.	.	28·75	230
Iodide of silver	.	.	.	29·5	236
Dichloride of mercury	.	.	.	29·5	236
Dichloride of gold	.	.	.	29·5	236
Dichloride of lead	.	.	.	30·5	244
Red antimony	.	.	.	31·5	252
Sesquiodide of antimony	.	.	.	31·625	253
Margaric acid	.	.	.	33	264
Biniodide of phosphorus	.	.	.	33·5	268
Oleic acid	.	.	.	32·25	258
Stearic acid	.	.	.	33·25	266
Indigotic acid	.	.	.	34·125	273
Dibromide of mercury	.	.	.	35	280
Terchloride of columbium	.	.	.	36·25	290
Diodide of mercury	.	.	.	40·75	326
Periodide of phosphorus	.	.	.	41·375	331
Trisiodide of gold	.	.	.	53·25	426
Arseniet of antimony	.	.	.	68·75	550

TABLE III.

EXHIBITING THE ATOMIC WEIGHT OF BODIES ARRANGED
ALPHABETICALLY.

A

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hydr. =
Acetic acid	6·25	50
in crystals	7·375	59
Alcohol	2·875	23
Alumina	2·25	18
Aluminum	1·25	10
Ammonia	2·125	17
Ammonium ?	2·25	18
Antimonic acid	10·5	84
Antimonious acid	10	80
Antimony	8	64
Arsenic	4·75	38
Arsenic acid	7·25	58
Arseniet of antimony	68·75	550
Arsenietted hydrogen	4·9375	39·5
Arsenious acid	6·25	50
Azote	1·75	14

B

Barium	8·5	68
Barytes	9·5	76
Benzoic acid	15	120
Bibromide of selenium	25	200
Bibromide of tin	27·25	218
Bicarburet of hydrogen	1·625	13
Bichloride of bromine	19	152
molybdenum	15	120
platinum	21	168
selenium	14	112
titanium	12·25	98
tin	16·25	130
tungsten	21·5	172
Bihydrate of alumina	4·5	36
Biniodide of phosphorus	33·5	268
Binoxide of barium	10·5	84
manganese	5·5	44
molybdenum	8	64
Biphosphuret of sulphur	6	48
Bismuth	9	72
Bisulphide of antimony	12	96
carbon	4·75	38
hydrogen	4·125	33
molybdenum	10	80

| | ATOMIC WEIGHTS | |
	Oxygen = 1.	Hyd. = 1
Bisulphide of tungsten	16·5	132
Bisulphuret of calcium	6·5	52
cobalt	7·25	58
copper	8	64
iron	7·5	60
platinum	16	128
potassium	9	72
tin	11·25	90
Black cast iron	11·25	90
Boracic acid	3	24
Boron	1	8
Bromide of iron	13·5	108
lead	23	184
mercury	22·5	180
potassium	15	120
selenium	15	120
silver	23·75	190
sulphur	12	96
tin	17·25	138

C

Cadmium	7	56
Calcium	2·5	20
Camphoric acid	13·5	108
Carbazotic acid	24·5	96
Carbo-hydrogen	0·875	7
Carbon	0·75	6
Carbonic acid	2·75	22
Carbonic oxide	1·75	14
Carburet of phosphorus	2·75	22
Carburetted hydrogen	1	8
Cast iron, black	11·25	90
white	14·75	118
Chloric acid	9·5	76
Chloride of azote	19·75	158
barium	13	108
bismuth	13·5	112
cadmium	11·5	92
calcium	7	56
carbon	5·25	42
cobalt	7·75	62
copper	8·5	68
gold	17	136
iron	8	64
lead	17·5	140
lithium	5·25	42
magnesium	6	48
manganese	8	64
mercury	17	136

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hydr. = 1.
Chloride of molybdenum	10·5	84
nickel	7·75	·62
platinum	16	128
selenium	9·5	76
silicon	5·5	44
sodium	7·5	60
strontium	10	80
sulphur	6·5	52
tellurium	8·5	68
tin	11·75	94
zinc	8·75	70
Chlorine	4·5	36
Chlor-iodic acid	24·75	198
Chloro-carbonic acid	6·25	50
Chloro-chromic acid	11	88
Chloro-cyanic acid	7·75	62
Chloro-phosphuret of sulphur . . .	10·75	86
Chromic acid	6·5	52
Chromium	4	32
Citric acid	7·25	58
Citric acid crystals	9·5	76
Cobalt	3·25	26
Columbic acid	25·75	206
Columbium	22·75	182
Copper	4	32
Croconic acid	7·75	62
Cyanogen	3·25	26

D

Decihydrate of chlorine . . .	15·75	127
Deutoxide of azote . . .	3·75	30
hydrogen . . .	2·125	17
Dibromide of mercury . . .	35	280
Dichloride of calcium . . .	9·5	76
carbon . . .	6	48
copper . . .	12·5	100
gold . . .	29·5	236
lead . . .	30·5	244
mercury . . .	29·5	236
sulphur . . .	8·5	68
tin . . .	19	152
Dihydrate of silica . . .	5·125	41
Di-iodide of mercury . . .	40·75	236
Dioxide of gold . . .	26	208
Disulphuret of copper . . .	10	80
iron . . .	9	72
lead . . .	28	224
nickel . . .	8·5	68
mercury . . .	27	216

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hydr⁺ = 1

F

Fluo-boric acid	.	.	.	.	.	4·25	34
Fluorine	.	.	.	.	.	2·25	18
Fluo-silicic acid	.	.	.	.	.	3·25	26
Formic acid	.	.	.	.	.	4·625	37
Fuming sulphuric acid	.	.	.	.	11·125	89

G

Gallic acid	.	.	.	.	.	8	64
Glucina	.	.	.	.	.	3·25	26
Glucinum	.	.	.	.	.	2·25	18
Gold	.	.	.	.	.	12·5	100

H

Hexacarbo-hydrogen	.	.	.	.	5·25	42
Hydrate of alumina	.	.	.	.	3·375	27
silica	.	.	.	.	3·125	25
Hydriodic acid	.	.	.	.	15·875	25
Hydrobromic acid	.	.	.	.	10·125	81
Hydrocarburet of chlorine	.	.	.	6·25	50
iodine	.	.	.	17·5	140
Hydrocyanic acid	.	.	.	.	3·375	27
Hydrofluoric acid	.	.	.	.	2·375	19
Hydrogen	.	.	.	.	0·125	1
Hydrosulphurous acid	.	.	.	14·375	115
Hyponitrous acid	.	.	.	.	4·75	38
Hypophosphorous acid	.	.	.	5·5	44
Hyposulphurous acid	.	.	.	5	40
Hyposulphuric acid	.	.	.	.	9	72

I

Indigotic acid	.	.	.	.	34·125	274
Iodic acid	.	.	.	.	20·75	166
Iodide of barium	.	.	.	.	24·25	194
bismuth	.	.	.	.	24·75	198
cadmium	.	.	.	.	22·75	182
calcium	.	.	.	.	18·25	146
carbon	.	.	.	.	16·5	132
copper	.	.	.	.	19·75	158
iron	.	.	.	.	19·25	154
lead	.	.	.	.	28·75	230
mercury	.	.	.	.	28·25	226
phosphorus	.	.	.	17·75	142
potassium	.	.	.	.	20·75	166
silver	.	.	.	.	29·5	236
sodium	.	.	.	.	18·75	150

		ATOMIC WEIGHTS	
		Oxygen = 1	Hydr = 1.
Iodide of strontium	. . . . .	21·25	170
sulphur	. . . . .	17·75	142
tin	. . . . .	23·	184
zinc	. . . . .	20	160
Iodine	. . . . .	15·75	126
Iridium	. . . . .	12·25	98
Iron	. . . . .	3·5	28

L

Lead	. . . . .	13	104
Lime	. . . . .	3·5	28
Lithia	. . . . .	1·75	14
Lithium	. . . . .	0·75	6

M

Magnesia	. . . . .	2·5	20
Magnesium	. . . . .	1·5	12
Manganese	. . . . .	3·5	28
Manganesic acid	. . . . .	6	48
Margaric acid	. . . . .	33	264
Mellitic acid	. . . . .	6·5?	52?
Mercury	. . . . .	12·5	100
Molybdenum	. . . . .	6	48
Molybdic acid	. . . . .	9	72
Mucic acid	. . . . .	13	104
Muriatic acid	. . . . .	4·625	37

N

Naphthaline	. . . . .	12·5	100
Nickel	. . . . .	3·25	26
Nitric acid	. . . . .	6·75	54
Nitrous acid	. . . . .	5·75	46

O

Olefiant gas	. . . . .	1·75	14
Oleic acid	. . . . .	32·25	258
Osmium	. . . . .	12·5	100
Oxalic acid	. . . . .	4·5	36
Oxide of antimony	. . . . .	9·5	76
bismuth	. . . . .	10	80
cadmium	. . . . .	8	64
copper	. . . . .	5	40
gold	. . . . .	14	112
iridium	. . . . .	13·5	108
mercury	. . . . .	13·5	108

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hydr. = 1.
Oxide of palladium	7·75	62
selenium	6	48
silver	14·75	118
tellurium	5	40
zinc	5·25	42
Oxychloride of sulphide of carbon	13·75	110
Oxygen	1	8

P.

Palladium	6·75	54
Perbromide of phosphorus	27	216
Perchloric acid	11·5	92
Perchloride of antimony	19·25	154
manganese	14·75	118
phosphorus	15·5	124
Perfluoride of manganese	9·125	73
Perhydrate of iron	6·125	49
Periodide of phosphorus	41·375	331
Peroxide of calcium	4·5	36
cerium	7	56
cobalt	4·75	38
iron	5	40
lead	15	120
nickel	4·75	38
platinum	14	112
potassium	8	64
rhodium	8·25	66
sodium	4·5	36
strontian	7·5	60
tin	9·25	74
uranium	28	224
Persulphuret of arsenic	22·75	182
bismuth	13	104
Persulphide of antimony	13	104
Phosphoric acid	4·5	36
Phosphorous acid	3·5	28
Phosphorus	2	16
Phosphuret of barium	10·5	84
chromium	6	48
copper	6	48
Phosphuretted hydrogen	3·375	27
Platinum	12	96
Protochloride of phosphorus	6·5	52
Protohydrated sulphuric acid	6·125	49
Protosulphuret of potassium	7	56
Protoxide of azote	2·75	22
cerium	6·5	52
chlorine	5·5	44
chromium	5	40

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hydr. = 1.
Protoxide of cobalt	4·25	34
gold	13·5	108
iron	4·5	36
lead	14	112
manganese	4·5	36
molybdenum	7	56
nickel	4·25	34
platinum	13	104
rhodium	7·75	62
Protoxide of tin	8·25	66
uranium	27	216
Potash	6	48
Potassium	5	40
Q		
Quaterchloride of azote	19·75	158
Quateroxide of chlorine	8·5	68
Quatersulphuret of potassium	13	104
Quatersulphide of molybdenum	14	112
Quintosulphuret of barium	18·5	148
calcium	12·5	100
copper	14	112
potassium	15	120
R		
Red antimony	31·5	252
Rhodium	6·75	54
S		
Selenic acid	8	64
Seleniet of arsenic	9·75	78
Selenietted hydrogen	5·125	41
Selenious acid	7	56
Selenium	5	40
Sesquibromide of antimony	23	184
arsenic	19·75	158
phosphorus	17	136
Sesquichloride of antimony	14·75	118
arsenic	11·5	92
carbon	7·5	60
gold	19·25	154
iron	10·5	84
phosphorus	8·75	70
Sesquifluoride of antimony	11·375	91
arsenic	8·125	65
Sesquifluo-silicic acid	3·875	31
Sesquihydret of phosphorus	2·1875	17·5

	ATOMIC WEIGHTS.	
	Oxygen = 1.	Hydr. = 1.
Sesqui-iodide of antimony	31·625	253
arsenic	28·375	227
carbon	24·375	195
phosphorus	25·625	205
Sesquioxide of cobalt	4·75	38
lead	14·5	116
manganese	5	40
Sesquiphosphuret of sulphur	5	40
Sesquisulphuret of arsenic	7·75	60
iron	6·5	52
selenium	8	64
tin	10·25	82
Sesquisulphide of antimony	11	88
gold	15·5	124
platinum	15	120
Silica	2	16
Silicet of carbon	1·75	14
hydrogen	1·125	9
Silicon	1	8
Silver	13·75	110
Soda	4	32
Sodium	3	24
Stearic acid	33·25	266
Strontian	6·5	52
Strontium	5·5	44
Suberic acid	12·5	100
Suboxide of copper	9	72
manganese	4	32
mercury	26	208
platinum	25	200
silver	21·625	173
Subsulphurous acid	3	24
Succinic acid	6·25	50
Sulphide of arsenic	9·75	78
hydrogen	2·125	17
Sulpho-chromic acid	11·5	92
Sulphur	2	16
Sulphuret of arsenic	6·75	54
barium	10·5	84
bismuth	11	88
boron	3	24
cadmium	9	72
calcium	4·5	36
chromium	6	48
cobalt	5·25	42
copper	6	48
iron	5·5	44
lead	15	120
lithium	2·75	22
magnesium	8·5	28

	ATOMIC WEIGHTS	
	Oxygen = 1	Hydr. = 1
Sulphuret of manganese	5·5	44
mercury	14·5	146
nickel	5·25	42
platinum	14	112
silicon	3	24
silver	15·75	126
sodium	5	40
strontian	7·5	60
tin	9·25	74
uranium	28	224
zinc	6·25	50
Sulphuric acid	5	40
ether	4·625	38
Sulphurous acid	4	32

T

Tannin	8·75?	70?
Tartaric acid	8·25	66
Tartaric acid crystals	9·375	75
Telluretted hydrogen	4·125	33
Tellurium	4	32
Terchloride of columbium	36·25	290
molybdenum	19·5	156
tungsten	26	208
Teroxide of chlorine	7·5	60
Tersulphide of columbium	28·75	230
molybdenum	12	96
tungsten	18·5	148
Tersulphuret of potassium	11	88
Tetartocarbo-hydrogen	3·5	28
Tetra-sulphuret of iron	16	128
Thorina	8·5	68
Thorium	7·5	60
Tin	7·25	58
Titanic acid	5·25	42
Titanium	3·25	26
Trishydrate of silica	7·125	57
Trisiodide of gold	53·25	426
Trisphosphuret of copper	14	112
Tritocarbo-hydrogen	2·625	21
Tungsten	12·5	100
Tungstic acid	15·5	124

U, V

Vinic acid	8·25	66
Uranium	26	208
Uric acid	9	72
metals	11·25	90

| | ATOMIC WEIGHTS. | |
| | Oxygen = 1. | Hyar. = 1. |

W

	Oxygen = 1.	Hyar. = 1.
Water	1·125	9
White cast iron	14·75	118

Y

Yttria	5·5	44
Yttrium	4·5	36

Z

Zinc	4·25	34
Zirconia	3·75	30
Zirconium	2·75	22

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